

DOE/CE-0008

JUN 5 1981

Survey
E 1.89:0008

429-14-4

Project Summary Data

Physical and Chemical Energy Storage Program

ORIGINAL

FY 1980

March 1981

COMPLETED
148

U.S. Department of Energy

Assistant Secretary for Conservation and Renewable Energy
Office of Advanced Conservation Technologies



I

Available from:

**National Technical Information Service (NTIS)
U.S. Department of Commerce
5285-Port Royal Road
Springfield, Virginia 22161**

**Price: Printed copy: \$12.50
 Microfiche: 3.50**

DOE/CE-0008

Dist. Category UC-94a, 94b, 94d, 94e

Project Summary Data

Physical and Chemical Energy Storage Program

FY 1980

March 1981

U.S. Department of Energy

Assistant Secretary for Conservation and Renewable Energy

Office of Advanced Conservation Technologies

Washington, D.C. 20585



III

CONTENTS

FOREWORD

THERMAL ENERGY STORAGE

INTRODUCTION	1
BUILDING HEATING AND COOLING APPLICATIONS	3
UTILIZATION OF WASTE HEAT - INDUSTRIAL	16
THERMAL ENERGY STORAGE RESEARCH AND DEVELOPMENT AND ANALYSIS AND ASSESSMENTS	20
THERMAL ENERGY STORAGE FOR SOLAR THERMAL APPLICATIONS	29

CHEMICAL/HYDROGEN ENERGY STORAGE

INTRODUCTION	39
CHEMICAL HEAT PUMP	41
CHEMICAL ENERGY SYSTEMS	46
HYDROGEN PRODUCTION	48
MATERIALS AND STORAGE SYSTEMS	62

MECHANICAL, MAGNETIC, AND UNDERGROUND ENERGY STORAGE

INTRODUCTION	70
FLYWHEEL ENERGY STORAGE	72
MAGNETIC ENERGY STORAGE	92
COMPRESSED AIR ENERGY STORAGE	96
SEASONAL THERMAL ENERGY STORAGE	112

FOREWORD

The Department of Energy's Office of Advanced Conservation Technologies (ACT) is developing cost-effective, efficient, reliable, and environmentally acceptable energy storage systems. These systems allow (1) stationary energy sources to serve mobile energy uses in vehicles, (2) intermittent energy sources (such as the sun) to serve continuous energy demands, and (3) constant energy sources to serve variable demands.

The mission of the Energy Storage Program is to develop devices, processes, and subsystems which permit domestic energy resources to be supplied at the time and locations where they can be used. In this program, energy is stored in thermal, chemical, mechanical, and magnetic forms. Generally, the best storage device for a specific supply system is one which minimizes the need for converting from one energy form to another in the overall system which consists of production, storage, transportation, and end-user equipment.

The Office of Advanced Conservation Technologies' Physical and Chemical Energy Storage Division during FY 1980 supported a broad range of projects to conserve energy and to make possible shifting away from oil and natural gas by developing new and/or improved energy storage systems applicable to central power generation, dispersed power generation, solar and waste heat utilization, and vehicle propulsion. The programs include:

- (1) Thermal Energy Storage
- (2) Chemical/Hydrogen Energy Storage
- (3) Mechanical and Magnetic Energy Storage; and
- (4) Underground Energy Storage (includes Compressed Air Energy Storage, Underground Pumped Hydro, and Seasonal Thermal Energy Storage)

The payoff is mainly in reduced oil imports through expanded production and use of coal, nuclear, and solar energy sources.

In FY 1980 ACT committed \$31.9 million to the Physical and Chemical Energy Storage Program. The breakdown of budget authorized funding is shown for the programs in the table below.

<u>Activity</u>	<u>Budget Authority</u>
	<u>(Dollars in Millions)</u>
	<u>FY 1980</u>
Thermal Energy Storage	8.2
Chemical/Hydrogen Energy Storage	5.4
Mechanical/Flywheel Energy Storage	4.5
Magnetic Energy Storage	1.2
Underground Energy Storage	8.9
Technical and Economic Analysis	1.6
Capital Equipment	<u>1.1</u>
	31.9

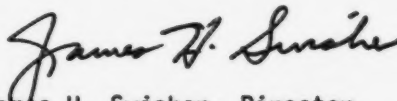
This publication consists principally of summary sheets for each active project in the Chemical/Hydrogen, Thermal, Magnetic, Mechanical, Flywheel and Underground Energy Storage Program for FY 1980. Each Summary includes: Project Title, Principal Investigator, Organization, Project Goals, Project Status, Contract Number, Contract Period, Funding Level and Funding Source.

An overview section is given before each set of project summaries. Detailed presentations were made early in the fiscal year at the following contractor review meetings:

- (1) Thermal and Chemical Energy Storage, October 14-16, 1980, Westpark Hotel, McLean, VA.
- (2) Mechanical, Magnetic, and Underground Energy Storage, November 10-12, 1980, Bethesda Marriott, Bethesda, MD.

The proceedings of each of these meetings have been published separately.

The Physical and Chemical Energy Storage Systems Division staff wishes to acknowledge the assistance of William Frier, who served as editor of this report.



James H. Swisher, Director
Division of Physical and Chemical
Energy Storage Systems
Office of Advanced Conservation
Technologies

THERMAL ENERGY STORAGE

INTRODUCTION

Thermal energy or heat can be stored as sensible heat, as latent heat, or by reversible chemical reaction.

Latent and particularly sensible heat storage systems have demonstrated performance that make them attractive for near-term uses. Substantial thermal storage promise is offered by new concepts such as low temperature heat storage in aquifers and high temperature and sensible heat storage in molten salt. (The discussion on aquifers is included within the Seasonal Thermal Energy Storage program within the Underground Energy Storage Program).

Sensible or latent heat thermal storage materials must be maintained at temperatures above that of the final use in order to transfer heat, while substances that undergo reversible chemical reactions can in principle, store thermal energy at ambient conditions. This potential makes reversible chemical reactions candidates for long duration storage and/or transport of thermal energy since material problems can be minimized.

The following applications areas have received the greatest emphasis in FY 1980 for Thermal Energy Storage:

- o Residential and Building Heating and Cooling Storage;
- o Storage for Industrial Heat Recovery, and;
- o Thermal Storage for Solar Thermal Power Generation.

Thermal energy storage technologies are expected to have significant near-term and mid-term impact in building heating and cooling applications. Thermal energy storage is vital in passive solar heating systems (collection, storage, and distribution of solar-thermal energy by components that are built into the structure). Customer-side-of-the-meter thermal storage of off-peak electric energy for residences and commercial buildings is a form of load management for the electric utilities. Low temperature thermal energy storage also improves the economics of active solar heating systems.

Major considerations impacting the development of solar thermal power systems for commercial applications are the need to buffer insolation changes, to provide continuous operation during periods of variable insolation, to extend operation into nonsolar hours, and to insure the availability of productive capacity in emergency periods. Although conventional backup systems provide a viable near-term answer to many of these needs, some thermal energy storage is needed to at least provide a buffering capacity. Storage capacities of three to six hours have promise for the near to mid-term, and long-term storage will

be needed if solar thermal systems are to perform independently of utility grids or to provide baseload electric generating for process heat plants.

Generic research and development (R&D) and systems analysis and assessments are vital components of the Thermal Energy Storage Program. The generic R&D activities are directed toward providing a technology base for application area. Research is performed for technologies with significant payoff and high risk such as thermochemical storage and transport. The information provided by the generic R&D allows the storage developers to decide which advanced storage candidates best meet their needs.

System analyses are also performed to identify the best thermal storage technologies for specific application areas. Finally, continual assessment of the thermal storage technologies and the applications areas guarantees that storage systems are developed which meet the end-use needs. Coordination between the thermal storage developers and the application users is included in this element.

The principal contact for these activities at DOE Headquarters is:

Michael Gurevich - Thermal Energy Storage

The principal contacts for these activities of responsibility at field operations are:

James Martin - Building Heating and Cooling and
Oak Ridge National Laboratory Industrial Heat Recovery Storage

William Wilson - Solar Thermal Power Storage
Sandia National Laboratories
Livermore

Charles E. Wyman - Generic Research and Development and
Solar Energy Research Institute Heat Transport

BUILDING HEATING AND COOLING APPLICATIONS

PROJECT SUMMARY

Project Title: Simulation and Evaluation of Latent Heat Thermal Energy Storage/Heat Pump Systems

Principal Investigator: T. W. Sigmon

Organization: Research Triangle Institute
P. O. Box 12194
Research Triangle Park, North Carolina 27709
Phone (919) 541-5878

Project Goals: To develop a simplified computer simulation of the performance of TES/Heat Pump systems and compute and compare system life cycle costs at various simulation sites.

Project Status: Technical tasks have been completed and final report is being prepared.

Contract Number: DE-AC-01-79ET-26707

Contract Period: 7/12/79 to 7/11/81

Funding Level: \$78,000

Funding Source: Division of Energy Storage, Department of Energy

PROJECT SUMMARY

Project Title: Storage Assisted Air Conditioning

Principal Investigators:

1. Joseph E. Rizzuto
New York State Energy Research
and Development Authority
Empire State Plaza
Albany, New York 12223
(518) 465-6251
2. Fred Avril
Long Island Lighting Company
250 Old Country Road
Mineola, New York 11501
(516) 228-2042
3. Maurice Lang
Institute of Energy Conversion
One Pike Creek Center
Wilmington, Delaware 19808
(302) 995-7155

Project Goals: The primary objectives of this program are to design and demonstrate a storage-assisted air conditioning system using CHUBS which will impose the minimum electric demand on the utility system. The CHUB storage system contains a Glauber's salt-based phase change material which will be evaluated under actual service conditions. Also to be evaluated under the program are: air conditioner system performance; energy storage sub-system performance; electrical demand and energy requirements; temperature and humidity control capability; and system cost.

Project Status: The tasks of this program include system design, parts procurement and fabrication, system and instrumentation installation, checkout, system test and monitoring, and analyses and reporting. The storage-assisted air conditioning system and instrumentation were installed in July of 1980. System checkout was completed during the first week of August. The system was operational as of August 8, however, system optimization and refinement of the data collection process will be on-going throughout the program.

Data will be taken throughout the remainder of this air conditioning season and during next season as required.

Contract Number: 194-31501V

Contract Period: August 1979 - December 1980

Funding Level: \$50,000

Funding Source: \$25,000 - Oak Ridge National Laboratory
\$25,000 - New York State Energy Research
and Development Authority

PROJECT SUMMARY

Project Title: Experimental Evaluation of Thermal Energy Storage

Principal Investigators: J.G. Asbury and H.N. Herish

Organization: Special Projects Group, Energy and Environmental Systems Division
Argonne National Laboratory
Argonne, IL 60439

Project Goals:

- Experimentally determine the technical performance of commercially available TES residential heating units under severe U.S. weather conditions.
- Assess the benefits and costs of TES to the customer, the utility and society.
- Determine user acceptance of TES.
- Identify and define TES issues, R&D needs and barriers to commercialization.
- Establish optimal sizing procedures.
- Establish uniform TES testing standards.

Project Status:

- A data base has been developed based on two heating seasons and 45 test and 30 control homes in Maine and Vermont. Based on an analysis of monitored temperatures and electrical energy used for space heating, fuel bills and reports of users and utilities, the technical performance of TES ceramic and hydronic systems is deemed to be satisfactory.
- An assessment of the benefits and costs of customer-owned TES for residential and commercial applications indicates that the net returns to society of such investments exceed their costs by a substantial margin.
- A user survey by an independent organization indicates a high degree of customer acceptance and positive attitudes towards TES.
- At the end of the second heating season, the participating utility in Maine (Central Maine Power Co.) decided to promote TES in its service area in order to slow the growth of its peak capacity and to level the daily load.
- A calorimeter chamber has been built and standardized procedures for testing TES modular units are being developed as an aid to commercialization.

PROJECT SUMMARY

Project Title: Development of Optimum Process for Electron Beam Crosslinking of High Density Polyethylene Thermal Energy Storage Pellets, Process Scale-Up and Production of Application Quantities of Material

Principal Investigator: Ival O. Salyer

Organization: University of Dayton
300 College Park
Dayton, OH 45469
(513) 229-4235

Project Goals: The objectives of this project are to determine the irradiation conditions for preparing thermally form stable polyethylene pellets for thermal energy storage applications and to process 15,000 pounds of pellets which are suitable for full scale application tests.

Project Status: The electron beam irradiation conditions for the preparation of thermally form stable high density polyethylene pellets have been determined. The values of the enthalpy of fusion have been measured on the polyethylene pellets as a function of the irradiation dose. A 225 pound pellet bed has been cycled through the melting temperature for more than 100 melt-freeze cycles. The pellet bed has remained porous to the free flow of the heat exchange fluid and the pellets have retained their initial physical form throughout the testing. A 15,000 pound quantity of the pellets is presently undergoing irradiation processing and is expected to be completed during the month of August 1980. The irradiated high density polyethylene pellets are to be delivered to DOE for full scale thermal energy storage tests.

Contract Number: 7641

Contract Period: 1 April 1980 - 31 October 1980

Funding Level: \$42,000

Funding Source: Department of Energy
Division of Energy Storage
Oak Ridge National Laboratory

PROJECT SUMMARY

Project Title: Operation of a Thermal Energy Storage Test Facility

Principal Investigator: Mark P. Ternes

Organization: Oak Ridge National Laboratory
P.O. Box Y
Oak Ridge, TN 37830
(615)-574-0749

Project Goals: Design and build a thermal cycling facility for determining the behavior of full-scale TES units. The facility will have the capability for testing with both liquid (water, ethylene glycol solutions, and salt brines) and air transport at variable heat input/extraction rates over a temperature range from 0 to 140°C (32 to 284°F).

Determine the thermal behavior of prototype and existing (commercial) PCM TES systems in both heating and cooling modes. Develop improved and advanced storage systems. Propose performance standards.

Project Status: Construction of the liquid cycling loop has been completed. Thermal stratification tests for both hot and cold water are currently underway and will continue into November 1980. Testing and evaluation of four PCM TES units will immediately follow the stratification studies.

Detailed design of the air cycling loop will be initiated by FY 1981.

Contract Number: In-house

Contract Period: Continuing

Funding Level: \$200,000

Funding Source: Department of Energy
Thermal and Mechanical Energy
Storage Systems Division

PROJECT SUMMARY

Project Title: Thermal Energy Storage Testing Facility

Principal Investigator: Robert J. Schoenhals

Organization: Ray W. Herrick Laboratories
School of Mechanical Engineering
Purdue University
West Lafayette, Indiana 47907
Telephone: (317) 749-6321

Project Goals: Develop a prototype thermal energy storage (TES) testing facility for electrically heated TES units that can be duplicated at established commercial or government laboratories, or at TES manufacturers' R & D laboratories. Provide technical information to assist ASHRAE in its effort to establish a standard for performance evaluation of electrically heated TES units.

Project Status: A calorimeter chamber has been fabricated and instrumented for testing of room-size TES units. Apparatus has also been assembled for testing of central TES units. One central unit and several room-size units have been tested. Variations in test procedure and apparatus configuration have been investigated both analytical and experimentally, and information based upon the results has been provided to ASHRAE.

Contract Number: ANL 31-109-38-4666

Contract Period: January 2, 1979 - September 30, 1980

Funding Level: \$98,170

Funding Source: Argonne National Laboratory
Energy & Environmental Systems Division
Special Projects Group

PROJECT SUMMARY

Project Title: Technology Development of Earth Storage

Principal Investigator: M. P. Ternes

Organization: Oak Ridge National Laboratory
P.O. Box Y
Oak Ridge, TN 37830
(615)-574-0749

Project Goals: Develop technology and demonstrate systems for utilizing heat stored in undisturbed earth for improving the performance of heat pumps.

Carry out field experiments to determine storage characteristics of undisturbed earth under residential buildings (crawl space) and its effects on performance of heat pumps for both heating and cooling. Develop computer models of the crawl space and heat pump to investigate system performance and economics in different climatic regions throughout the nation. Demonstrate crawl space heat pump systems.

Project Status: Winter operating data from three field experiments has been collected and is currently being digitized, with data reduction and analysis to follow. Collection of summer operating data from three field experiments is underway. The computer model of the crawl space is complete and will be checked against the actual data now being digitized. Crawl space simulations will begin following this comparison. Heat pump models are currently under development. Planning for a definitive test addressing concept performance and economics has begun.

Contract Number: In-house

Contract Period: Continuing

Funding Level: \$85,000

Funding Source: U.S. Department of Energy
Thermal and Mechanical Energy
Storage Systems Division

PROJECT SUMMARY

Project Title: Mathematical and Physical Modeling for TES Subsystems

Principal Investigator: A. D. Solomon

Organization: Oak Ridge National Laboratory
Building 9704-1
P.O. Box Y
Oak Ridge, TN 37830
Telephone: (615) 574-8696

Project Goals: Develop capability for predicting the performance of TES subsystems and components using PCM's based on mathematical and physical models. Similarly, perform simulations of processes relevant to TES subsystem performance, and develop mathematical tools and techniques for predicting the behavior of PCM's undergoing changes of phase.

Project Status: A number of computer simulation programs have been prepared, of varying flexibility and applicability. The first, TES, permits us to simulate a simple body undergoing a phase change process due to forcing conditions at its surface of Dirichlet, flux or convective type. This has been specialized to a model of the behavior of a system of PCM containers and used to perform simulations of arrays of University of Delaware Chubs with the inclusion of dehumidification effects for the air transfer fluid. The latter includes the possibility of transfer fluid flow reversal at specified times. A second simulation model prepared is that of heat conduction with phase change in a block of earth beneath the crawl space of a house, interacting with air flowing through the crawl space. The model has thusfar been compared favorably with data obtained from a test house. Comparisons of computer simulation predictions with experimental results obtained for melting and solidification experiments with N-Octadecane Paraffin wax have been completed. In the past year closed form, easily computable expressions have been obtained for the melting time of a rectangular body and for a simple body with a convective heat transfer at its surface. These relations are extensions of the work of earlier years, aimed at obviating the necessity of performing lengthy computations in the search for answers to specific problems arising in sizing systems and estimating system performance.

The tasks for FY 80 will be: 1) Completion of simulation programs for phase change with natural convection in the melt, which are currently being developed; 2) Derivation of a closed form expression for the melting time and heat flux behavior in a body subject to a radiation (fourth power) boundary condition; 3) Development and study of simulation models for more advanced systems, and the development of techniques for deriving the maximum

information from them with the least computational effort.

Contract Number: W-7405-eng-26

Funding Source: U.S. Department of Energy

Project Summary

Project Title: Thermal Energy Storage for Residential Energy Conservation

Principal Investigator: David Goldenberg

Organization: TRW Inc.
Energy Systems Group
P. O. Box 3007
Oak Ridge, Tennessee 37830
Telephone: 615/482-9054

Project Goals: Evaluate the potential of thermal energy storage applications involving passive solar systems and waste heat recovery from fossil-fueled furnaces for gas and oil conservation in the residential sector.

A pebble bed device was analyzed for improvements in furnace seasonal efficiency. Passive solar systems were analyzed for fossil energy conservation benefits.

Project Status: Final report was submitted to Oak Ridge National Laboratory on July 31, 1980, in draft form for review.

Contract Number: 62B-13817C, Letter Release 62X-11

Contract Period: December 1979 - July 1980

Funding Level: \$60,000

Funding Source: Oak Ridge National Laboratory

PROJECT SUMMARY

Project Title: Survey of Thermal Storage Installations in the United States and Canada

Principal Investigator: Harold G. Lorsch

Organization: Franklin Research Center
20th and the Parkway
Philadelphia, PA 19103
(215) 448-1591

Project Goals: Create an inventory of thermal storage installations, for either hot or cold storage or both, in commercial and industrial use in the United States and Canada. This inventory will then be published in a special brochure by ASHRAE in order to obtain the broadest dissemination among designers and potential users.

Project Status: A team of mail and telephone inquirers has been organized at the Franklin Research Center. A Technical Evaluating Committee (TEC) has been created by ASHRAE (American Society of Heating, Refrigerating and Air Conditioning Engineers). This TEC is to oversee the progress of the project and to ensure that the results are valid and that the ensuing publication meets the publication standards of ASHRAE.

A questionnaire has been designed and approved by the ASHRAE TEC. In excess of 100 letters have been mailed out. Major source publications have been obtained.

Contract Number: BOA 41B-28915C

Contract Period: July 2, 1980 to September 30, 1980
(to be extended)

Funding Level: \$24,000

Funding Source: Department of Energy/UCC Subcontract

Project Title: Evaluation of Olivine Ceramic Refractories for Thermal Energy Storage Applications

Principal Investigators: Hayne Palmour III, Billy M. Gay and R. L. Cochrane

Organization: North Carolina State University
Engineering Research Services Division
P. O. Box 5995
Raleigh, NC 27650
(919) 737-2351 (or 2347)

Project Goals: The principal objectives of this program are to (1) experimentally determine the degree of improvement in thermal and mechanical performance that can be obtained with an olivine thermal storage brick made of domestic materials using advanced processing techniques compared with state-of-the-art as represented by commercial European bricks, (2) conduct an assessment of existing German ceramic process technology and determine its adaptability to domestic raw materials and manufacturing practices, and (3) investigate, on a limited basis, methods for further improvement of domestic olivine brick.

Project Status: New Contract (since August 18, 1980), continuing previous work initiated January, 1978 by the University and supported in part by the North Carolina Energy Institute from June, 1978 through March, 1980. Prior accomplishments of that program have been reported in two prior papers and a Technical Report, and are briefly summarized in the attached paper.

Tasks under the present program include (1) installation and use of improved, computer-based instrumentation for performance evaluations of heat storage refractories under cyclic use conditions, (2) acquisition of the services of a European consultant knowledgeable about West German materials and processes for ceramic heat storage applications, and (3) continuing lab-scale process/property optimization studies. At this early stage, equipment orders have been placed, program planning and software development are underway, and arrangements are being made to bring the chosen consultant to the U.S. for analysis and discussions of established European technology.

Contract Number: US DOE Contract No. W-7405-eng-26, Union Carbide Corporation, Nuclear Division Subcontract No. 7959

Contract Period: August 18, 1980 - November 30, 1981

Funding Level: \$73,013.00

Funding Source: Department of Energy through Union Carbide Corporation, Nuclear Division (ORNL).

PROJECT SUMMARY

Project Title: Evaluation of Stratified Thermal Storage System for Oliver Springs Elementary School

Principal Investigators: R.L. Reid and A.F.G. Bedinger

Organization: The University of Tennessee
Energy, Environment, and Resources Center
329 South Stadium Hall
Knoxville, Tennessee 37916
615-974-4251

Project Goals: A combination refrigeration heat recovery system and stratified thermal storage system using a flexible membrane to resist temperature blending will be evaluated. The evaluation will consist of two related parts: 1) evaluation of overall HVAC system thermal performance and comparison with alternate systems and 2) evaluation of the flexible membranes ability to resist temperature blending.

Project Status: The Oliver Springs Elementary School is under construction with an expected completion date of January 1981. Installation of the data acquisition system is underway with data gathering expected to begin in January 1981.

Contract Number: 7685 (Project Authorization X60)

Contract Period: June 1, 1980 through November 30, 1980

Funding Level: \$64,888

Funding Source: Union Carbide Corporation
Nuclear Division

UTILIZATION OF WASTE HEAT – INDUSTRIAL

PROJECT SUMMARY

Project Title: Aluminum Waste Heat for Bellingham District Heating

Principal Investigator: Lincoln B. Katter

Organization: Rocket Research Company
York Center
Redmond, WA 98052
Telephone: (206) 885-5000

Project Goals: Assess the economic viability and public acceptance of a district heating system in Bellingham, Washington.

Conduct a review of the technological impact on the Intalco aluminum plant.

Evaluate other thermal energy sources for backup.

Evaluate institutional considerations.

Perform a detailed system cost analysis.

Project Status: All tasks are proceeding on schedule.

Contract Number: 86Y-4253C

Contract Period: April 1979 to November 1980

Funding Level: \$1,000,000

Funding Source: ORNL

PROJECT SUMMARY

Project Title: Collection and Dissemination of Thermal Energy Storage System Information for the Pulp and Paper Industry

Principal Investigator: Howard Edde, Ph.D., P.E.

Organization: Howard Edde, Inc. Consulting Engineers
Rockwood Office Park
1402 140th Place N.E.
Bellevue, Washington 98007
(206) 643-0900

Project Goals: Recent studies have indicated that substantial reductions in a pulp and paper mill's net energy requirements can be realized by application of thermal energy storage (TES) system technology. This concept is not as widely applied today in the U.S. pulp and paper industry as it is in some international mills, especially with Scandinavia. The main objectives of this project are the collection and dissemination of TES system technology for the U.S. pulp and paper industry with the intent of reducing fossil fuel usage.

Project Status: The tasks of this project include: (1) survey of the U.S. and international industries to identify TES systems and define their operational characteristics; (2) a benefit analysis which includes an energy conservation assessment, and economic analysis and an environmental impact assessment; and (3) information dissemination which includes a brochure, a display and presentation of papers at conferences.

A survey of North American and international pulp and paper mills was conducted to identify the existing applications of TES systems, to obtain and analyze the operation data from a representative number of these mills and to transfer this information to the U.S. pulp and paper industry. The survey was recently completed and the results are available to indicate that a number of typical TES case example situations exist which are believed to have a high potential for application within the U.S. industry. Table 1 presents some of these mills conditions selected for detailed investigation. The results of the overall study will be completed by early 1981.

(Continued)

Project Status:

Table 1

TES System Applications Studies

Production Type ton/year (metric)		Application
Dissolving Newsprint	140,000 245,000	Steam accumulator TES system to store steam during paper machine breaks
Sulfate (sack)	170,000	Mill owned boiler to provide district heating for adjacent community. TES system is hot water accumulator for mill transient hot water energy demands. Start-up scheduled September 1980, permitting before/after evaluation of energy demands.
Sulfite (Unbleached)	160,000	
Newsprint	170,000	Steam accumulator TES system to store steam during paper machine breaks and utilize steam when paper sheet is brought to full width.
Dissolving Sulfite	150,000	Boiler feedwater modulation.
Sulfate	218,000 (pulp) 286,000 (paper)	Steam accumulator for balancing steam production from recovery boiler in relation to batch digesters and board machine.

Contract Number: DEN3-190
 Contract Period: February 1980 - May, 1981
 Funding Level: \$114,000
 Funding Source: Department of Energy

PROJECT SUMMARY

Project Title: Bellingham Project, Preliminary Assessment of the Once-Through District Heating System

Principal Investigator: Dr. I. Olikar

Organization: Burns and Roe, Inc.
Power Technology Division
800 Kinderkamack Road
Oradell, NJ 07649
(201) 265-2000

Project Goals: The main objective of this project is to develop, in a conceptual form, the once-through heat supply arrangement and compare with two-pipe heat transport design.

Project Status: The tasks in this project include (1) assessment of the heat load data, (2) development of the conceptual design of the once-through heat supply system, (3) cost estimates of the transmission and distribution piping system, thermal storage facility, and water makeup system.

Accomplishments to date include tasks (1) and (2).

Contract Number: Supplemental Agreement No. 2 to Subcontract No. 7672 to Union Carbide Corporation.

Contract Period: August 1980 - October 1980.

Funding Level: \$37,893.

Funding Source: Department of Energy.

**THERMAL ENERGY STORAGE RESEARCH AND DEVELOPMENT
AND ANALYSIS AND ASSESSMENTS
PROJECT SUMMARY**

Project Title: The SERI Solar Energy Storage Program

Principal Investigator: Charles E. Wyman

Organization: Solar Energy Research Institute
1617 Cole Boulevard
Golden, Colorado 80401
(303) 231-1753

Project Goals: The overall objective of this program is to gain a better understanding of advanced thermal energy storage technologies for specified applications and obtain the data and information that will allow developers to select the most promising thermal energy storage technologies for identified applications. Research is performed on direct contact heat exchange and thermochemical storage and transport to provide a basis from which to assess these promising technologies. Research is subcontracted to define new thermal energy storage and transport concepts. Analyses, research, and development are supported to improve the cost and performance of thermal energy transport concepts. Systems analyses identify thermal energy storage concepts for solar thermal applications. Finally, efforts are directed to help coordinate thermal energy storage programs.

Project Status: Preliminary analyses and experiments have been completed for direct contact heat exchange and equipment has been assembled to test the concept further. An analysis has been made of thermochemical storage and transport. Cost goals based on value have been derived for thermal energy storage in solar thermal electric applications and preliminary rankings have been completed of thermal storage for water/steam and organic fluid receiver systems. A workshop has been conducted to review progress on the Thermal Energy Storage for Solar Thermal Applications Program, and a basis has been developed for coordination of thermal energy storage R & D for solar heating and cooling of buildings.

Contract Number: EG-77-C-01-4042

Contract Period: October 1979-September 1980

Funding Level: \$1,505,000

Funding Source: Department of Energy Division of Thermal and Mechanical Energy Storage Systems.

PROJECT SUMMARY

Project Title: Latent Heat Storage Research

Principle Investigator: John D. Wright

Organization: Solar Energy Research Institute
Solar Thermal Research Branch
1617 Cole Blvd.
Golden, Colorado 80401
(303) 231-1765

Project Goals: The goals of the latent heat storage research project are to understand the basic mechanisms which govern direct contact heat transfer, assess the operational characteristics of direct contact salt hydrate/oil latent heat storage systems, and provide a basis for selecting, assessing, and designing advanced storage concepts.

Project Status: A model of direct contact heat transfer in salt hydrate/oil systems has been developed which shows reasonable agreement with the limited experimental data available, and identifies controlling mechanisms for direct contact heat transfer. Experiments have been carried out to test methods of predicting drop size and to determine the heat transfer characteristics of droplets. An experiment has been constructed to test holdup predictions and to assess operational characteristics.

Contract Number: EG-77-C-01-4042

Contract Period: October 1979-September 1980

Funding Level: \$170,000

Funding Source: Department of Energy Division of Thermal and Mechanical Energy Storage Systems.

PROJECT SUMMARY

PROJECT TITLE: Systems Analysis of Thermal Storage

PRINCIPAL INVESTIGATOR: R.J. Copeland

ORGANIZATION: Solar Energy Research Institute
1617 Cole Blvd.
Golden, CO 80401
(303) 231-1012 (FTS-327-1012)

PROJECT GOALS: The objective of this project is to identify promising thermal storage concepts for research and development. The value of thermal storage concepts in solar thermal applications is analyzed to establish cost goals. Thermal Storage concepts are compared to each other using a consistent costing approach and accounting for the performance differences between the concepts. The best concept for specific applications are recommended for continued development. Analyses of new concepts and applications are also conducted to identify promising areas for research.

PROJECT STATUS: During FY80 a preliminary screening of thermal storage concepts was conducted. Solar thermal electric power production with a water/steam receiver (Barstow Technology) and a solar thermal total energy system with an organic fluid receiver (Shenandoah Technology) were the applications. Promising concepts for each were identified. The analysis is being extended to more applications (electric power, process heat and total energy) with water/steam, organic fluid, and air/Brayton solar thermal systems. A SERI subcontractor, Stearns-Rogers, is providing consistently calculated cost and performance data of the thermal storage concepts. Based on that data, SERI will analyze the impacts on delivered energy cost and recommend concepts for continued development.

A ranking of thermal storage technologies based upon value for solar thermal electric power systems was performed. For diurnal applications, second generation thermal storage technologies must be improved 30% to 70% over first generation thermal storage technologies to meet the value derived cost goals. Potential long duration storage technologies were identified.

The value of thermal storage in solar thermal process heat systems is currently being studied. In addition ground mounted thermal storage concepts for a dish/stirling system are being evaluated.

CONTRACT NUMBER: EG-77-C-01-4042

CONTRACT PERIOD: October 1979 - September 1980

FUNDING LEVEL: \$310,000

FUNDING SOURCE: Department of Energy, Division of Energy Storage

PROJECT SUMMARY

Project Title: Cost and Performance of Thermal Storage Concepts in Solar Thermal Systems

Principal Investigator: A.W. McKenzie

Organization: Stearns-Roger Inc.,
P.O. Box 5888,
Denver, Colorado 80217

Project Goals: The objectives of this study are as follows:

To provide consistently calculated cost data for several thermal storage concepts integrated into solar thermal systems.

To provide consistent and realistic performance data for storage concepts integrated into solar thermal systems.

To provide the above data as projected for a mature technology based upon the state-of-the-art and anticipated improvements in the storage technologies.

Project Status: The following has been accomplished in the course of the study of this point:

Available thermal concepts have been reviewed through a literature search, and contracts with the Solar Energy Research Institute, national laboratories, and other contractors.

Reference systems were established in which the storage systems were compared.

The systems selected for further study were established on the basis of a developed set of screening criteria.

Schematics were developed for the remaining forty systems.

Quantities were established for the above and rough-order-of-magnitude (ROM) costs computed.

Based on the ROM costs and the screening criteria, candidates for further study were selected.

Schematics will be more fully developed and costing will be further refined for these twenty remaining systems.

A technical review will be held in September, 1980 of these systems.

The results of the technical review will be incorporated into the systems. Their storage range will be expanded, and further costing refinements applied.

The results of the thermal storage analysis will be documented in a final report.

Subcontract Number: XP-0-9001
Contract Period: March 1980 - March 1981
Funding Source: Solar Energy Research Institute

PROJECT SUMMARY

Project Title: High Temperature Molten Salt Thermal Energy Storage

Principal Investigator: T. D. Claar, R. J. Petri

Organization: Institute of Gas Technology
3424 South State Street
Chicago, Illinois 60616
(312) 567-3650

Project Goals: The main objective of this program is to select and screen in 1000 and 3000 hour compatibility tests latent-heat alkali and alkaline earth carbonate storage salts, containment materials, and thermal conductivity enhancement (TCE) materials to satisfy the high temperature (704° to 871°, 1300° to 1600°F) thermal energy storage requirements of advanced solar-thermal power generation concepts. The results of these compatibility tests will lead to selection of the materials combinations that best meet the anticipated solar power system requirements.

Project Status: The tasks in this program include: 1) Materials Compatibility Testing -- Materials Selection (Salt, Containment, and Thermal Conductivity Enhancement Materials Selection), 1000 Hours Compatibility Testing, and 3000 Hour Compatibility Testing; and 2) Salt Property Measurements. Accomplishments to date include completion of materials investigation and selection; assembly of capsules for total testing matrix; completion of 1000 hour compatibility testing; initiation of post-test examination and preliminary evaluations.

The tasks for FY 80 include: 1) completion of 3000 hour matrix selection and testing 2) completion of thermophysical and transport property measurements on two most promising salts.

Contract Number: DEN3-156

Contract Period: September 1979 - September 1980

Funding Level: \$136,000

Funding Source: NASA-Lewis Research Center for U.S. Department of Energy

PROJECT SUMMARY

Project Title: Active Heat Exchanger System Development for Latent Heat Thermal Energy Storage System

Principal Investigator: J. Alario, R. Haslett

Organization: Grumman Aerospace Corporation
Bethpage, N.Y. 11714
Telephone: (516) 575-2433/3924

Project Objectives: Develop an active method of heat exchange in a latent heat (salt) thermal storage system that prevents a low thermal conductivity solid salt layer from forming on heat exchanger surfaces.

Project Status: A modular test unit of 10KW heat transfer rate and 10KW-Hr storage was designed and fabricated. Two interchangeable heat exchanger modules can be used to investigate heat transfer by 1) direct contact between salt and a liquid metal eutectic and 2) scraping the solidifying layer off a rotating drum. The concept selection, evaluation and design phases of the program have been published in Topical Report No. NASA CR 159726 (January 1980).

The test evaluation phase for the direct contact heat exchanger concept was started mid-February 1980, but was interrupted in June due to funding limitations. Various problems with the pumps, plumbing leaks and corrosion failure of electrical heaters contributed to delays. At the time of interruption, due to extensive heater failures, the media transfer technique had been verified, liquid metal was circulated through the heat exchanger, all system components were preheated and the salt system was about to be activated.

The program is in a hold status awaiting hardware refurbishment and heater replacement.

Contract Number: DEN 3-39

Contract Period: 6/13/78 to 8/13/80

Funding Level: \$225,000

Funding Source: NASA-Lewis Research Center

PROJECT SUMMARY

Project Title: Heat-of-Fusion Energy Storage-Boiler Tank

Principal Investigator: Dr. Talbot A. Chubb

Organization: Naval Research Laboratory
Code 4120
Washington, DC 20375
Telephone: (202)767-3580

Project Goals: Demonstration feasibility of heat-of-fusion energy storage-boiler tank.

Evaluate media and heat transfer fluid properties and cycle life characteristics.

Perform storage media-containment materials compatibility studies.

Design, build, and operate a 2 MWh storage-boiler tank.

Project Status: Completed site preparation. Completed detailed design of such items as pressure containment vessel, boiler, terphenyl circulation system, basket to hold salt cans, etc.

Published Progress Report which includes further study of Heat-of-Fusion Energy Storage Systems using containerized salts.

Procured major components such as terphenyl pump, feedwater pump, insulation, heaters, control parts, etc.

Fabricated 90% of pressure containment vessel and fabricated prototype of baskets required to hold salt cans.

Contract Number: EC-77-A-31-1024

Contract Period: July 1976 to January 1981

Funding Level: DOE - \$460,000; NRL - \$360,000

Funding Source: DOE-Division of Energy Storage Systems and NRL

PROJECT SUMMARY

Project Title: Heat Storage in Alloy Transformations

Principal Investigator: C. E. Birchenall

Organization: University of Delaware
Materials/Metallurgy Faculty
College of Engineering
Newark, DE 19711
(302) 738-2194

Project Goals: The primary purpose was to show that congruent solid to liquid transformations of metals and alloys provided energy storage densities that are high enough to compete with other storage materials, mainly inorganic salts. In addition to measuring transformation energies for melting of pure metals and alloy eutectics, expansion coefficients of solids and melts and volume changes during transformation were sought. Preliminary information on chemical stabilities of container materials has been obtained.

Project Status: Calorimetric measurements have been done on the transformation of aluminum and a wide selection of its alloys containing copper, magnesium, silicon, zinc, calcium and phosphorus. These data, combined with those obtained in earlier studies, appear to be sufficiently precise and to cover a sufficient number of cases to give a representative picture of the thermal performance that can be expected of eutectic alloys in the 600 to 1200 K range. Numerous alloys, having heats of transformation from 210 to 545 kJ/kg, cover this range so that few large temperature gaps exist. Measurements of representative alloys show that volume changes during transformation are on the order of 5 pct. Some salts show volume changes up to 5 times greater. The alloys have been handled successfully in the laboratory in graphite containers. SiC and other carbides probably would not be attacked by these alloys.

The major goals of this project have been met, and evaluation of alloys relative to other storage materials is going forward. It is anticipated that new support will be sought for the design and construction of container vessels and channels that are iron-based alloys protected by carbide coatings. The central issue will be whether a system can be fabricated then coated or whether the alloy pieces must be coated prior to final shaping, joining and finishing.

Contract Number: NSG-3184

Contract Period: July 1, 1978 - November 30, 1980

Funding Level: \$183,783

Funding Source: NASA Grant with funds from U. S. Department of Energy,
Division of Energy Storage Systems

THERMAL ENERGY STORAGE FOR SOLAR THERMAL APPLICATIONS

PROJECT SUMMARY

Project Title: Thermal Energy Storage for Solar Thermal Applications (TESSTA)

Principal Investigator: L. G. Radosevich

Organization: Sandia National Laboratories
Organization 8453
P. O. Box 969
Livermore, CA 94550

Project Goals: The overall objective of this storage development program is to develop general solar thermal energy storage technologies that provide:

- Second-generation storage subsystems offering cost/performance improvements over the first-generation storage subsystems currently being developed for solar thermal power applications.
- First-generation storage subsystems for those solar thermal applications that presently have no storage subsystems under development.
- A technology base to support storage subsystem development for future solar thermal power applications.

Implementation of the first two program elements, which are application oriented, is the responsibility of Sandia National Laboratories. Implementation of the technology base goal is the responsibility of the Solar Energy Research Institute (SERI). The program is organized through a work breakdown structure which includes the development of thermal storage technologies matched to solar thermal power system requirements for several near-term applications. Solar thermal power systems include troughs, dishes, and central receivers with working fluids at various operating conditions.

Project Status: The TESSTA program was initiated in FY80. Contracts have been awarded and in-house studies are underway in support of three high priority applications: 1) repowering/industrial retrofit; 2) total energy; 3) small community experiments.

Contract Number: AN-35, PACE 35-AL-10

Contract Period: October 1979-September 1980

Funding Level: \$3,000.00

Funding Source: Department of Energy

PROJECT SUMMARY

Project Title: Molten Nitrate Salt Technology Development

Principal Investigator: R. W. Carling

Organization: Sandia National Laboratories
Division 8453
Livermore, CA 94550

Project Goals: The overall objective of this project is to develop a technology base for the use of molten nitrate salts as a heat transfer and energy storage medium in central receiver applications.

Project Status: Contracts have been awarded and in-house experimental studies are underway.

Contract Number: AN-35, PACE 35-AL-10

Contract Period: October 1979 - September 1980

Funding Level: \$700,000

Funding Source: Department of Energy

PROJECT SUMMARY

Project Title: Molten Nitrate Salt Chemistry Studies

Principal Investigator: S. H. White

Organization: EIC Laboratories, Inc.
55 Chapel Street
Newton, MA 02158
(617) 965-2710

Project Goals: The objective of this program is to provide a thorough understanding of the interactions of molten potassium nitrate, sodium nitrate, and their binary mixtures with water and carbon dioxide in the air. These studies will complement ongoing work at Sandia into the development of molten nitrate mixtures for application as heat transfer and sensible heat storage media in large solar energy power systems. The results of these studies will help to determine whether an open, closed or breathing system is needed in salt storage.

Project Status: To accomplish these goals, electroanalytical techniques are being applied to identify the interactions of water, carbon dioxide and air with the melts as a function of temperature. The rates of change of reactants and the rates of formation of products will be measured by electroanalysis. A combination of the rotating disc method and cyclic voltammetry or chronopotentiometry or chronoamperometry will enable the solution concentrations and the mass transfer rates to be uniquely determined. A literature survey to review the known chemistry and electroanalytical chemistry of nitrates has been carried out. Preliminary experiments to explore the behavior of water, carbon dioxide, and air in contact with the molten nitrate salts together with a supplementary investigation of the response of potential degradation products such as hydroxide, carbonate, and nitrite ions has been accomplished.

Contract Number: Sandia 20-2991

Contract Period: July 1980 - July 1981

Funding Level: \$76,200

Funding Source: Sandia National Laboratories

PROJECT SUMMARY

Project Title: Mass-Transfer Characteristics of Nitrate-Based Salt Mixtures

Principal Investigator: J. H. DeVan

Organization: Oak Ridge National Laboratory
Metals and Ceramics Division
P. O. Box X
Oak Ridge, TN 37830
(615) 574-4451

Project Goals: The objective of this program is to determine the corrosion kinetics of Fe-Cr-Ni alloys in flowing eutectic $\text{KNO}_3\text{-NaNO}_3$ salt as a function of temperature change along the salt flow path.

Project Status: Eutectic $\text{KNO}_3\text{-NaNO}_3$ is being circulated in thermal convection loops constructed of 304 SS, 316 SS, and Alloy 800, respectively. The loops are operating at a maximum salt temperature of 595°C and a salt temperature gradient of 235°C . Insert specimens are contained within each loop for determination of weight changes, corrosion product scales, and microstructural changes and will be examined after 500, 1500, and 4500 h, respectively. Voltammetry techniques developed for fluoride salt studies at ORNL are being used to monitor the oxidation potential of the nitrate salt as a function of corrosion reactions occurring in the loop system.

Contract Number: Sandia Lab P.O. # 92-85-68

Contract Period: March 1980 to April 1981

Funding Level: \$65,500

Funding Source: Department of Energy

PROJECT SUMMARY

Project Title: Corrosion Behavior of Alloys

Principal Investigator: R. A. Osteryoung

Organization: Department of Chemistry
State University of New York at Buffalo
Buffalo, New York 14214
(716) 831-3820

Project Goals: The objective of this work is to study the chemistry of solutes in molten nitrates at temperatures in the 450-500°C range to obtain information which will permit an understanding of the corrosion behavior of structural alloys, such as Incoloy 800, that will be employed in thermal loops in solar power systems. Solute of interest are those which may be expected to result from the corrosion of these structural alloys, i.e., iron, nickel, chromium in particular. Ultimately, studies related to the formation of passivating films on appropriate alloys will be performed, and the effect of impurities, such as nitrite, hydroxide and chloride, will be investigated.

Project Status: This work has just recently been initiated; equipment for electrochemical studies has been ordered, cell design and construction is underway; familiarization with literature pertaining to prior studies in molten nitrates has been undertaken. Discussion with Sandia representatives has indicated that the heretofore unknown corrosion behavior of molten nitrates at these elevated temperatures is perhaps more severe than we originally anticipated, based on prior, but lower temperature, work. As a result, initial experiments will be performed in platinum or gold containers in quartz containment vessels.

Contract Number: 20-4478

Contract Period: May 5, 1980 - June 30, 1981

Funding Level: \$85,100

Funding Source: Sandia Laboratories
Livermore, CA 94550

PROJECT SUMMARY

Project Title: Experimental and Theoretical Investigation of Thermocline Degradation

Principal Investigator: J. A. C. Humphrey

Organization: Department of Mechanical Engineering
University of California, Berkeley
Berkeley, California 94720
(415) 642-6460

Project Goals: There are four:

- 1) To obtain flow visualization and temperature measurements in a laboratory-scale experiment which simulates the basic characteristics of a thermocline storage system under a variety of operating conditions.
- 2) To provide a one-dimensional model describing the behavior of the laboratory thermocline storage system based on closed form solution of the energy transport equation and known boundary conditions.
- 3) To predict numerically the fluid-mechanical and heat transport aspects of the laboratory thermocline storage system, especially those features related to buoyant effects and diffuser performance.
- 4) To provide a comparative evaluation between experiment, theoretical and numerical analyses.

Project Status:

- 1) The experimental system is presently being completed and will be ready for operation by mid-August. It consists of a large plexiglass tank of rectangular cross-section and includes conducting and non-conducting side walls, variable aspect ratio and diffuser controlled constant temperature flow into and out of the tank.
- 2) The transient theoretical analysis has been completed. It is now being written into the form of a FORTRAN program. The next steps include testing, debugging and applying the code to the lab-scale system.
- 3) Transient, 2-D, laminar flow, numerical calculations of thermocline degradation including buoyant effects are presently being made for test cases corresponding to the experiment. They will be evaluated during the months of August and September.

Contract Number: 482447-26966

Contract Period: October 1979 - September 1980

Funding Level: \$35,542

Funding Source: DOE, through Sandia Laboratories
Livermore, California

PROJECT SUMMARY

Project Title: Dish Mounted Latent Heat Buffer Storage
Principal Investigator: R. Manvi
Organization: Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, California 91103
(213) 577-9349

Project Goals: The development of parabolic dish mounted latent heat storage subsystems for three small community system applications. Power conversion cycles under consideration include Rankine, Brayton, and Stirling Operating at temperatures of 427°C (800°F), 816°C (1500°F), and 816°C (1500°F), respectively. The task provides for storage requirements definition, conceptual design, media stability and compatibility tests, thermal performance analyses, cost estimates, and subsystem research experiments (SRE).

Project Status: Three separate industrial contracts awarded to identify and define buffer storage requirements for the dish mounted Rankine, Brayton, and Stirling engines, respectively.

Review of phase change material candidates and their containment completed, and selections made.

Review of Receiver integrated latent heat buffer storage concepts completed, and recommendations made.

High temperature (1500°F) material corrosion experiments initiated with NaCl, Na-NaCl, NaF-MgF₂ contained in SS316, SS321, SS430, 9Cr-1 Mo alloy steel. The experiments include natural convection loops and capsules.

Computer code developed for the transient analyses of a receiver integrated with latent heat storage.

An industrial contract awarded for the study of solidification control of PCM on heat transfer surfaces.

Contract Number:
Contract Period:
Funding Level:
Funding Source:

SLL Purchase Order 92-8545
FY 1980
\$ 550K
Sandia Laboratories, Livermore, California

PROJECT SUMMARY

Project Title: Storage Requirements Definition and SRE Design for Dish Stirling Systems

Principal Investigator: W.F. Zimmerman

Organization: General Electric Company
Advanced Energy Programs Department
P.O. Box 15132
Cincinnati, OH 45215
(513) 243-5294

Project Goals: The objective of the program is to assess the performance and economic merits of the use of latent heat thermal energy storage in point focussing solar Stirling power conversion systems. Comparisons are to be made between two types of solar receivers with and without the presence of a fossil fuel combustor and with amounts of storage time appropriate to the system design. Additional concepts for TES are to be identified, the developments required to promote the economic and performance acceptability of the TES concepts are to be specified and the nature of worthwhile subscale research experiments to demonstrate the technical and cost feasibility of TES concepts are to be defined.

Project Status: Both receiver systems have been modeled for finite element thermal performance analysis. Solar insolation and other weather data in one minute increments over a one year period at the test site have been received in tape form and processed into a mass data file suitable for data acquisition in the computer analysis program. The economic factors and the capital costs and operating and maintenance costs effecting the cost of electricity have been established. The system models have been checked out using brief spans of solar data and the basic comparison cases are ready to run.

Contract No.: JPL 955388

Contract Period: April 3, 1980 - December 15, 1980

Funding Level: \$85,212

Funding Source: JPL/DOE

PROJECT SUMMARY

Project Title: Thermal Storage Requirement Definition Studies for Task 10 of The Small Community Solar Thermal Power Experiment

Principal Investigator: R. E. Polzien

Organization: Ford Aerospace & Communications Corporation
Aeronutronic Division
Ford Road
Newport Beach, California 92660
(714) 759-5925

Project Goals: The objective of this program is to study the application of a latent heat thermal energy buffer storage (TEBS) to the Small Community Solar Thermal Power Experiment (SCSE). The SCSE is a 1-MW_e electrical power generation system using multiple point focusing distributed receiver power modules equipped with organic Rankine Cycle power conversion units. The TEBS study goals are: 1) to establish the need and size of a latent heat TEBS, 2) to identify design concepts which are generally compatible with the SCSE power module design and cost and weight goals, 3) to identify and recommend component and subsystem development needs, and 4) to define subscale experiments for hardware demonstration of a selected concept.

Project Status: The tasks in this program include requirement studies, parametric evaluation of alternate TEBS design concepts, identification of development requirements, and definition of subscale hardware demonstration requirements. Accomplishments to date include performance and economic evaluation of the SCSE plant with and without a TEBS under time varying insolation conditions for an entire year using an FACC developed computer program.

The studies have identified the TEBS capacities and charge/discharge rate capabilities required to produce efficient and stable plant operation under conditions of intermittent insolation dropout. Preliminary design analyses have also been performed which define the performance, size, and mechanization requirements of alternate TEBS concepts.

The remaining tasks, for FY80 include completion of concept evaluation design studies, 2) selection of a best design concept, 3) detailed design analyses and study of development requirements for the selected design, and 4) design of a subscale experiment to demonstrate hardware.

Contract Number: 955637 - Modification No. 3

Contract Period: May 1980 - November 1980

Funding Level: \$73,750

Funding Source: Jet Propulsion Laboratory

CHEMICAL/HYDROGEN ENERGY STORAGE

INTRODUCTION

Hydrogen generated from non-fossil energy sources has a potential as an energy storage medium for use in chemical feedstocks, natural gas supplements, utility load leveling, and alternative transportation fuels. Hydrogen activities under development in FY 1980 included: (1) electrochemical production systems; (2) thermochemical production systems; (3) chemical heat pumps; (4) chemical storage systems and materials; and (5) end-use applications and systems studies.

Major sources of hydrogen are natural gas, light oils, coal, and water. With the long-term prospect of declining fossil fuel supplies, water is the primary choice as a feedstock for large-scale future hydrogen production. The project goals are to increase the efficiencies and decrease the costs of producing hydrogen by electrolytic and cyclic thermochemical water splitting processes.

For the near-term, hydrogen production will be limited by the available energy sources and the economy of the current production technologies. At present, most hydrogen is produced from natural gas and oil feedstocks. Coal will replace portions of these feedstocks. Today, the only commercially used non-fossil-fueled process for hydrogen production is electrolysis of water. Most electrolyzers are used to produce hydrogen for laboratories, food processors, semi-conductor manufacturers, and similar users for whom the cost is an obvious technology to be advanced for commercialization.

The electrolytic method of hydrogen production is a relatively simple process. The hydrogen and oxygen products are easily separable from the water feedstock, and no byproducts or pollutants are emitted at the production site. The main impediment to early large-scale commercialization of this technology is the cost of input for electric power.

To compensate for the increasing cost of power, one of the primary Chemical/Hydrogen Storage objectives is to increase electrolysis efficiency. This requires high-reaction rates which are governed by temperatures, choice of electrode/electrolyte materials, and catalysts.

Thermochemical water splitting is another method of providing a non-fossil renewable source of hydrogen. The general method of thermochemical water splitting is to drive a series of chemical reactions by supplying energy, usually heat, and accomplishing hydrogen and oxygen release in separate chemical steps. Objectives are to avoid high temperatures (above 2500°C) of direct thermal decomposition of water and to reduce the electricity requirements for the electrolysis of water.

The overall goal in the hydrogen storage area is to develop new technology and materials for the safe storage of hydrogen in large quantities as for electric utility use, and in small amounts for uses as a fuel for automobiles and as a substitute for propane in rural areas. The four basic methods for hydrogen storage currently in use and under development include compressed gas, cryogenic liquid, metal hydrides or other occluder materials, and underground or undersea storage. The first two methods are in commercial use. Work on metal hydrides and other occluder materials for stationary and vehicular storage applications is in progress, and an assessment was conducted to verify that underground storage is feasible.

The transport of hydrogen, particularly as large volumes of compressed gas, and related short duration storage are integral parts of nearly all gaseous hydrogen systems. Widespread distribution of gaseous hydrogen in residential and commercial applications appears to be a far-term possibility, the implementation of which will require improved technologies.

Hydrogen use is concerned with all aspects of implementing complete systems where hydrogen is either an end-product or is used in a conversion process as an energy carrier.

The principal contact for these activities at DOE Headquarters is:

Fred Gornick - Hydrogen/Chemical

The principal contact for these activities of responsibility at field organizations are:

Alessio Mezzina - Chemical Heat Pump/Hydrogen Storage
Brookhaven National Laboratory

Douglas Miller - Thermochemical Production
Brookhaven Area Office

CHEMICAL HEAT PUMP

PROJECT SUMMARY

Project Title: International Energy Agency Program on Hydrogen Production

Principal Investigator: James H. Swisher (for DOE)

Organization: Division of Thermal and Mechanical Energy Storage Systems,
U.S. Department of Energy, 600 E Street, N.W.,
Washington, D.C. 20585
(202) 376-4919

Project Goals: Accelerate technology development in the production of hydrogen from water through international cooperation.

Project Status: Information and personnel exchange is now in progress in five project areas: thermochemical production, low temperature electrolysis, high temperature electrolysis, photocatalytic processes, and market projections. A final report on hydrogen market projections will be published shortly. Experimental work on the various production processes is proceeding at a steady pace, although no significant new discoveries have been made. Bench-scale facilities for thermochemical hydrogen production have been built and operated both in the U.S. and in Europe. One U.S. scientist has worked at a Commission of European Communities laboratory for six months under the Agreement and several European scientists have worked at U.S. labs for shorter periods. At least one workshop has been held each year for each activity to accomplish exchange of results and ideas. Some task sharing of projects has evolved since the Agreement was signed.

Contract Number: None

Contract Period: October, 1977, to October, 1980. Continuation likely.

Funding Level: U.S. Dept. of Energy - \$6 million; IEA total-\$20 million in FY 1980.

PROJECT SUMMARY

Project Title: Sulfuric Acid/Water Chemical Heat Pump

Principal Investigator: E. C. Clark

Organization: Rocket Research Company
Redmond, Washington
(206) 885-5000

Project Goals: The project is structured to verify the capability of the sulfuric acid-water system and to enhance near-term commercialization. The primary objective is to design, construct and test a sulfuric acid CHP/CES verification test unit (VTU) which incorporates as many commercial, mass producible design features as necessary to demonstrate system economic and technical feasibility. The VTU will be designed to function both as a storage HVAC unit and a temperature enhancement industrial heat pump. For purposes of gaining scaling criteria, the nominal storage design capacity shall be 10^6 Btu with a nominal delivered heat rate of 150,000 Btu/hr.

Project Status: Rocket Research is currently under contract to Brookhaven National Laboratory to conduct a four-phase program. Phases 1 and 2 are completed and consisted of a requirement analysis and detailed design of the VTU. Generic applications have been identified which include industrial waste heat pumping, space conditioning, air or gas moisture removal, steam accumulation, cogeneration and energy storage. The VTU design incorporates two of the above designs: waste heat pumping and space conditioning. The design incorporates combined generator/condenser and absorber/evaporator reaction components made of steel shells coated with acid resistant porcelain. Teflon-lined acid plumbing and valves will be used and the acid storage tank will be fabricated from steel lined with porcelain and capable of vacuum operation.

The remaining Phases 3 and 4 consisting of VTU fabrication and testing, respectively, will be conducted in FY 81.

Contract No.: 494588-S

Contract Period: 1 October 1979 through September 1981

Funding Level: \$699,740

Funding Source: Brookhaven National Laboratory.

PROJECT SUMMARY

Project Title: Methanol-Based Heat Pump for Storage of Solar Thermal Energy

Principal Investigator: Dr. Peter O'D. Offenhartz

Organization: EIC Laboratories, Inc
55 Chapel Street
Newton, MA 02158
(617) 965-2710

Project Goals: The purpose of this system was to test a 100,000 BTU thermal storage capacity $\text{CaCl}_2\text{-CH}_3\text{OH}$ chemical heat pump and to evaluate the data obtained. Specific objectives were to 1) test the CaCl_2 reactor-heat exchanger design at a scale close to that which would be used in the field; 2) carry out off-design cycle tests, including simulated process upsets and control failure; 3) initiate and complete long-term (>100 cycles) testing; 4) evaluate salt bed heat exchanger performance; 5) calculate the system COPs for heating and cooling, including all parasitics; 6) evaluate overall performance and issue performance claims and specifications; and 7) issue a final report including a revised development plan.

Project Status: All tasks have now been completed. Cycling performance was excellent, although the heat exchangers showed some warpage due to plastic flow of the salt. The system appears impervious to process upset. The rate of reaction was a strong function of the temperature difference ΔT between the absorber heat transfer fluid and the evaporator, ranging from over 1.1 moles CH_3OH per mole CaCl_2 per hour at $\Delta T = 40^\circ\text{C}$ to 0.094 M/M/hr at $\Delta T = 55^\circ\text{C}$. The latter rate is still more than adequate for solar heat pumping. Performance degradation after 100 cycles, expressed as a contact resistance, was less than 2°C , and it appears that further cycling will not increase this resistance. The experimental COP for cooling was 0.52, close to the value expected theoretically (0.56). All performance objectives have been met, and our economic analysis indicates the system should prove cost effective.

Contract Number: BNL 490105-S

Contract Period: August 1979 - September 1980

Funding Level: \$193,398

Funding Source: Brookhaven National Laboratory

PROJECT SUMMARY

Project Title: A Cost-Effectiveness Evaluation of Several Chemical Heat Pump Systems

Principal Investigator: W. Standley, R. Gorman, P. Moritz, and T. O'Gorman

Organization: TRW Energy Systems Planning Division
8301 Greensboro Drive
McLean, Virginia 22102
(703) 734-6530

Project Goals: The objective of this project is to conduct an independent assessment of several chemical heat pump (CHP) systems providing HVAC services to both a residential and a commercial building, as well as one application in providing industrial process heat. The levelized annual cost of operation and ownership for the CHP systems will be compared to baseline systems and a set of emerging technologies. The baseline systems include conventional fossil fuel-fired heating systems, vapor-compression air conditioning, and electrically-driven heat pump HVAC. The emerging systems include solar-thermal (hydronic) heating, solar-driven absorption air conditioning, and vapor-compression heat pumps operating in the solar-assisted, ground-coupled, and aquifer-coupled modes.

Project Status: The tasks in this project involve collection and evaluation of existing cost and performance data for the baseline systems; adaptation of available data for the emerging systems; and detailed verification of cost and technical performance projections for the CHP systems of interest. The "standard" buildings in residential and commercial applications have been defined for two locations, Boston and Albuquerque. Each building in each location has been characterized with respect to HVAC requirements; HVAC system characteristics have been established; and the baseline and emerging HVAC systems have been run through the levelized-cost methodology.

The work for FY 81 will include completing the CHP system characterizations and working through the cost-effectiveness evaluation. A final report will summarize the results of the project, with the numerical results of the evaluation presented in sufficient detail to enable the reader to discern the impact of each component of levelized cost (i.e., the evaluation will be transparent.)

Contract Number: BNL 519403-S

Contract Period: June 9, 1980 through January 15, 1981

Funding Level: \$98,346

Funding Source: Brookhaven National Laboratory

PROJECT SUMMARY

Project Title: HYCSOS Chemical Heat Pump and Energy Conversion System based on Metal Hydrides

Principal Investigators: J. M. Clinch and J. S. Horowitz

Organization: Argonne National Laboratory
Chemical and Electrical Systems Programs
9700 S. Cass Avenue, Argonne, Illinois 60439
(312) 972-7693

Project Goals: The major objective of this program is to develop a metal hydride heat pump for residential, commercial, and industrial applications.

Project Status: In FY 1980, both experimental and analytical work has been performed. Both of these tasks focus on a tubular metal hydride heat pump design. The experimental work consists of testing and evaluating a tubular design heat exchanger manufactured by INCO. The test results will assist in providing information on the heat pump performance of realistic hydrides beds. The analytical work centers on developing an approach for predicting the Coefficient of Performance (COP) of a tubular heat pump. Thermodynamic and heat transfer models have been formulated to account for thermal regeneration modes. Calculations indicate that a COP of 1.55 for heating is obtainable with the tubular heat pump design. However, this result requires verification by experiment.

In addition to the above work, a request for a proposal (RFP) has been prepared by ANL and issued through Brookhaven National Laboratory (BNL) to select an industrial contractor for the design and engineering development of a prototype metal hydride heat pump. Proposals have been evaluated and recommendations are being made through BNL's office for a contract award.

Contract Number: AL-10-05-15/49405

Contract Period: October 1979 - September 1980

Funding Level: \$220,000

Funding Source: Department of Energy

CHEMICAL ENERGY SYSTEMS

PROJECT SUMMARY

Title: Hydrogen Chemical Compressor

Principal Investigator: P.P Turillion

Organization: Ergenics Division
MPD Technology Corporation
681 Lawlins Road
Wyckoff, NJ 07481
(201) 891-9103

Project Goals: Phase I: To build a bench scale metal hydride compressor prototype and evaluate its performance over several hundred cycles of operation. Phase II: To design and construct a scaled up hydride compressor coupled to an industrial water electrolyzer, and compare its performance and cost effectiveness in relation to a conventional compressor.

Project Status: The first phase was completed on July 15, 1980. The prototype HCC was successfully operated continuously, delivering 20.3 Std. liters per minute (43SCFH) of hydrogen at a pressure of 42.2 Atma (650 psia). After 700 cycles of operation a slight decrease in absorption capacity of hydride was observed. A capsule containing a sample of the hydrided material was removed from the compressor and analyzed. A decrease in plateau pressure was measured. The measured efficiency of the compressor (4.5%) was lower than the predicted practical efficiency (12%). The decrease in efficiency can be readily explained by the large amount of copper inherent in the design of the electrically heated bench scale prototype.

Contract No: 484822-S

Contract Period: Phase I, September 15, 1979 to July 15, 1980 Phase II duration 12 months in FY (if authorized)

Funding Level: Phase I DOE/BNL: \$46,436.00
Ergenics Cost Share 3,495.00
\$49,931.00 (7%)

Phase II (estimated) \$150K

Funding Source: DOE Chemical/Hydrogen Energy Storage Systems
Ergenics cost share 7% of Phase I.

PROJECT SUMMARY

Project Title: Development of a Commercial Metal Hydride Process for Hydrogen Recovery

Principal Investigator: Dr. E.L. Huston

Organization: Ergenics Division
MPD Technology
681 Lawlins Road
Wyckoff, NJ 07481
(201) 891-9103

Note: Air Products and Chemicals, Inc. and INCO Research and Development Center, Inc. are subcontractors.

Project Goals: The primary objective of this project is the development and commercialization of a process for recovering hydrogen from waste gas streams based on metal hydride technology. The waste gas streams exist in chemical plants and refineries with a total hydrogen content of 3,200 million SCF per day and a potential resource recovery of 0.1 Quad.

Project Status: Phase I - Process Identification was initiated 7/14/80. Initial Tasks include a survey of chemical and petroleum refineries to document waste gas streams and determine future H₂ resistant of AB, AB₂, and Mg hydride formers to the gaseous contaminants of these streams. Subsequent tasks include: evaluation of stream pretreatment/hydride regeneration options; process integration; assessment of process economics and preparation of a commercialization plan. A go/no-go decision will be made at the end of Phase I regarding follow-on phases.

Contract No.: BNL-509926-S

Contract Period: August 14, 1980 - October 31, 1981

Funding Level: Phase I - \$316,727
Subsequent phase(s) total about \$900,000 For a three-year program total of \$1,200,000

Funding Source: DOE CHEMICAL/HYDROGEN ENERGY STORAGE SYSTEMS Cost Sharing 14.75% or \$54,000 additional for Phase I.

HYDROGEN PRODUCTION

PROJECT SUMMARY

Project Title: Solid Polymer Electrolyte Water Electrolyzer Technology Development

Principal Investigator: J.H. Russel

Organization: General Electric Company
Direct Energy Conversion Programs
50 Fordham Road
Wilmington, MA 01887
(617) 657-5277

Project Goals: The main objective of this program is to develop a low-cost (<\$150/kW) hydrogen generation plant (200kW - 5MW) for electric utility/industrial chemical applications, using the solid polymer electrolyte technology. To minimize capital and operation costs, the goal is to generate hydrogen at high current densities (>1000 ASF) at pressures in the range of 100 to 300 psig, with an overall system efficiency of 85-90%.

Project Status: The tasks in this program include the analytical design, materials evaluation, mechanical scale-up and manufacturing process development necessary to fabricate and operationally test large-size cells. Accomplishments to date include assembly and operation of 2.5 FT² cells in 50kW (12-cell), 100kW (30-cell), and 200kW (60-cell) modules at up to 100 psi with average cell voltages of 1.85-1.89 VDC at 1000 ASF. Design of a scaled-up 10 FT² cell and module has been completed, and fabrication development has started.

Contract No: DE-AC02-78ET26202

Contract Period: FY 80 - FY 81

DOE Funding Level: Department of Energy and Co-Sponsors

PROJECT SUMMARY

Project Title: Advanced Alkaline Water Electrolysis

Principal Investigator: J. N. Murray

Organization: Teledyne Energy Systems
110 West Timonium Road
Timonium, MD 21093
(301) 252-8220

Project Goals: This project is directed toward identification of improved electrolysis module components which exhibit stable operation at operating temperatures at 100 to 150°C, operating current densities of approximately 500 ma/cm² and allow process efficiencies to approach 100%

Project Status: In GFY 1980, a fourth generation computer program was completed and tested which allows the determination of the optimal hydrogen economics via alkaline water electrolysis. The relative merits of improved electrodes, the effects of electrode operating temperature(s) and the optimal design current densities are among the features tested to date. The experimental verification of the stability of improved anodes was continued using the TES-C-AN cathode structure. Samples of two new potassium titanate electrode separators have been obtained for testing. An optimum component five-cell module will be assembled for extended testing in the Applied Research Industrial Electrolysis System (ARIES) in GFY 1981.

Contract Number: BNL 480421-S

BNL 507416-S

Contract Period: April 1979 - January 1980

February 1980 - February 1981

Funding Level: \$79,727

\$154,542

Funding Source: Brookhaven National Laboratory

Brookhaven National Laboratory

PROJECT SUMMARY

Project Title: Static Feed Water Electrolysis for Large Scale Hydrogen Generation

Principal Investigator: F. H. Schubert

Organization: Life Systems, Inc.
24755 Highpoint Road
Cleveland, OH 44122
(216) 464-3291

Project Goals: The primary objective of this program is to demonstrate the inherent capability of the alkaline electrolyte, Static Feed Water Electrolysis System (SFWES) to generate low cost hydrogen for chemical storage/industrial chemical applications.

Reductions in capital and operating costs will be addressed through₂ cell area scale-up demonstrations and studies (5_2ft^2); operation at high current density (1 amp/cm^2); demonstration of low cell voltage operation; and testing with contaminated feed water, e.g., simulated sea water, to eliminate water treatment expendables and equipment.

Project Status: Negotiations between Brookhaven National Laboratory and Life Systems, Inc. have been completed and a four task project is scheduled to start August 15, 1980. These tasks will address (1) elevated current density (1 A/cm^2) investigations, (2) contaminated water operation, (3) cell area scale-up and (4) future scale-up sequence for the total system. Accomplishments to date include project organization and layout and readying of the Contractor furnished test facilities and test cell hardware for task one.

All tasks will be completed during FY81 (by April, 1981), including printing and submittal of the Final Report.

Contract Number: 522723-S

Contract Period: August 1980 - April 1981

Funding Level: \$108,485

Funding Source: Department of Energy

PROJECT SUMMARY

Project Title: Selection and Evaluation of Materials for Advanced Water Electrolyzers

Principal Investigator: Glenn E. Stoner

Organization: University of Virginia
Applied Electrochemistry Laboratory
Materials Science Department
University of Virginia
Charlottesville, VA 22901
(804) 924-3277

Project Goals: The main objectives are to examine the potential-time behavior in alkaline electrolyzers; develop an understanding of these effects and report the causes and suggest possible solutions to the sponsor. Another goal is to initiate an examination of the electrocatalytic effects of high surface area polycrystalline nickel whiskers.

Project Status: Most of the voltage-time effects were reported to be at the cathode and were found, by electrochemical experiments and theoretical calculations to be consistent with the formation of a nickel hydride. Polycrystalline whiskers were encouraging on a per weight basis but more studies are required with regard to their properties as electrocatalysts. A Ph.D. dissertation by P. J. Moran was successfully prepared and defended.

Contract Number: BNL-4-51320-S

Contract Period: August 1979 - July 1980

Funding Level: \$22,000

Funding Source: BNL/DOE

PROJECT SUMMARY

Project Title: Analysis of Vehicle Systems Using Hydrogen Storage/Alkaline Fuel Cell Technology

Principal Investigator: S. Srinivasan

Organization: Brookhaven National Laboratory
Associated Universities, Inc.
Upton, New York 11973

Project Goals: The main objective of this program is to develop low cost fuel cells for vehicular applications. Since this is a new activity, the goal in FY 1980 is to generate sufficient information for delineation of a Development Plan for low-cost fuel cells applied to automotive systems.

Present Status: Single cell and multicell alkaline fuel cell units have been evaluated at BNL. Performance is at least twice that obtained in similar units about a decade ago. Los Alamos Scientific Laboratory (LASL) is carrying out a computer simulation to evaluate selected fuel cells and hydrogen storage subsystems in a typical consumer vehicle (based on a GM X-car).

The tasks for FY 1980 will be: 1) testing and evaluation of improved hydrogen electrodes in alkaline fuel cells; 2) completion of the computer simulation studies; 3) submission of a Development Plan.

Contract Number: DE-AC02-76CH00016

Contract Period: October 1979 - September 1980

Funding Level: \$150,000

Funding Source: Department of Energy

Project Summary

Project Title: Hydrogen Production from Small Hydropower Sites

Principal Investigator: New York State Energy Research and Development Authority

Organization: New York State Energy Research and Development Authority

Project Goals: Construction and operation of a hydropowered electrolysis facility.

Project Status: Completion of program plan.

Contract Number: DE-AC02-80ET26224

Contract Period: August 1, 1980 - December 1, 1983

Funding Levels: Phases I & II - \$174,900 (U.S. DOE)
Phases III & IV - Unfunded

Funding Sources: See Below

<u>ESTIMATED FUNDING:</u>	<u>Phases I & II</u>	<u>Phase III</u>	<u>Phase IV</u>	<u>Totals</u>
DOE/BNL	\$174,900	\$784,800	\$ 35,550	\$995,250
NYSERDA	\$145,100	\$758,500	\$ 75,550	\$979,150
Village	-0-	\$849,700	\$ 88,900	\$938,600
TOTALS	\$320,000	\$2,393,000	\$200,000	\$2,913,000

PROJECT SUMMARY

Project Title: Production Cost Comparisons of Hydrogen from Fossil and Nuclear Fuels and Water Decomposition

Principal Investigator: Karl R. Ekman

Organization: Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, California 91103
(213) 577-9020

Project Goals: The broad objective of this project was to examine the costs entailed in producing hydrogen by technologies that rely on petroleum, natural gas, coal, thermochemical cycles, and electrolysis. Techniques for comparing these processes were developed by formulating the process data and economic assessments on a uniform and consistent basis. These data were then normalized to permit a more valid and meaningful comparative analysis of the plant investments and product costs of these processes through the year 2020.

Project Status: Report finalized and issued July 1980. Conclusions reached were: Hydrogen production from natural gas is and remains the least expensive option through CY 2000, with hydrogen costs from petroleum increasing in the same ratio as natural gas. If hydrogen were produced from coal today, it would cost about the same as petroleum derived hydrogen. Thermochemical cycles are expected to become cost competitive with fossil fuels around 1995, assuming substantial process development continues and economics of large scale facilities are realized. The cost of producing hydrogen by electrolytic processes will remain high. By 1990, production of energy by high-temperature nuclear reactors may reach commercial feasibility and tend to stabilize overall production costs at about \$10/MBtu.

Contract Number: IA ET-78-1-01-3112 (One of several tasks)

Contract Period: FY'80

Funding Level: \$195K (FY'80) (For all tasks under IA ET-78-1-01-3112)

Funding Source: Department of Energy - STOR

PROJECT SUMMARY

Project Title: Advanced Hydrogen Production Concepts

Principal Investigator: D. D. Lawson

Organization: Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, California 91103

Project Goals: This activity monitors the technical progress and problems in the Advanced Hydrogen Production Concepts Element. The element has supported further development of the innovative and unusual technological findings that derive from creative basic research. It is not the intent of this activity to do fundamental or basic research, but only to extend work that has been described (literature, technical reports or by private communication) and to bridge the technology gap between very basic concepts and true larger scale applications.

Project Status: Five activities are involved in this element. The activities have been divided into two topic areas: Hydrogen Produced by Solar Radiation: 1. The hydrogen photoelectrolytic conversion activity (EIC Conf. Newton MA) has investigated practicability of semiconductor-electrolytic devices (similar to Honda-Fujishima) that use solar energy to decompose water into hydrogen and oxygen in an apparent single step process. Final report draft approved with the report due in October 1980. 2. The photocatalytic decomposition of inorganic hydrogen compounds; i.e., hydrobromic and hydriodic acids (Prof. Gray, CIT) using rhodium organic bridge complexes. The final report is in preparation. 3. Studies were conducted on the feasibility of direct high temperature thermal decomposition of water with diffusion processes for separation of the equilibrium mixture of hydrogen and oxygen into useable energy, sources (Battelle-Geneva). Report issued in June 1980. Conservation Activities: 1. A study (SRI) on the recovery of hydrogen from hydrogen sulfide was conducted. It developed a base line in terms of markets, economics and chemistry of the recovery of hydrogen from hydrogen sulfide streams in situations where hydrogen would otherwise be wasted. Report issued in December 1979. 2. Preliminary comments on the low temperature decomposition of sulfuric acid by use of high sulfur content coal to yield sulfur dioxide and carbon dioxide (JPL). Work in progress.

Contract Number: IA ET-78-1-01-3112 (One of several tasks)

Contract Period: FY'80

Funding Level: \$195K (FY'80) (For all tasks under IA ET-78-1-01-3112)

Funding Source: Department of Energy - STOR

PROJECT SUMMARY

Project Title: Production of Hydrogen by Electron Transfer Catalysis using Conventional and Photochemical Means

Principal Investigator: D. Paul Rillema*

Organizations: Jet Propulsion Laboratory
Pasadena, California - (Summer of 1980
DOE Faculty Exchange Program)
and
Department of Chemistry
University of North Carolina
Charlotte, North Carolina

Project Goals: The investigation of hydrogen production by use of electron transfer catalysts using energy from conventional or solar sources to drive the reactions.

Project Status: Work was done on alternate methods of preparing hydrogen from sulfuric acid by use of thermal or electrochemical cycles. A number of processes requiring chemical, electrochemical or photochemical methods were studied. These include the design of potential photoelectrodes and photocatalytic membranes using $\text{Ru}(\text{bpy})_3^{2+}$ (bpy = 2,2'-bipyridine) impregnated nafion tubing and the design of experiments to study the catalyzed electrolytic formation of hydrogen and sulfuric acid from sulfur dioxide and water using quinones as catalysts. Experiments were carried out to determine the value of the new approaches to energy conversion.

Contract Number: IA ET-78-1-01-3112 (One of several tasks)

Contract Period: FY'80

Funding Level: \$195K (FY'80) (For all tasks under IA ET-78-1-01-3112)

Funding Source: Department of Energy - STOR

PROJECT SUMMARY

Project Title: Thermochemical Water-Splitting Program

Principal Investigator: G. E. Besenbruch

Organization: General Atomic Company
General Programs Division
P.O. Box 81608
San Diego, CA 92138
(714) 455-2090

Project Goals: This program involves experimental research and development of the Sulfur/Iodine thermochemical water splitting cycle. Specific objectives include development of a bench-scale unit which demonstrates the major aspects of the cycle, and development of engineering flowsheets for estimation of process costs and efficiency. Funding of closely related work on cycle chemistry is provided by the Gas Research Institute. Funding on solar applications of the process is provided by DOE Solar Thermal Power Office and SERI.

Project Status: Installation of the bench-scale system was completed meeting a major milestone in the overall General Atomic thermochemical water-splitting program. Operation and preliminary data acquisition in the system resulted in verification of flowsheet conditions for all unit operations which were tested. A view and modification of flowsheet section III (HI purification) was carried out and resulted in an increase in process thermal efficiency of approximately 1.5% for the total process. Consequently the capital equipment requirements were significantly reduced. The Funk panel review of the GA process was completed. Unpublished results indicate that there appear to be no real technical problems in the process. Project work centers on data acquisition in the bench-scale equipment and on demonstrating the process in the integrated DOE-STOR bench-scale system.

Contract Number: DE-AC02-08ET26225

Contract Period: October 1979 - September 1980

Funding Level: 399,205 (DOE, FY1980)
130,000 (GRI, CY-1980)
55,000 (MPC, CY-1980)
55,000 (GA, CY-1980)
40,000 (GPL, CY-1980)
99,000 (SERI, CY-1980)

Funding Source: Department of Energy - STDR
Department of Energy - Solar Thermal Power Office
Gas Research Institute
Metal Properties Council
General Atomic Company
Jet Propulsion Laboratory (From DOE STOR)
Solar Energy Research Institute

PROJECT SUMMARY

Project Title: Thermochemical Processes for Hydrogen Production

Principal Investigator: Melvin G. Bowman

Organization: Los Alamos Scientific Laboratory
P. O. Box 1663, MS-756
Los Alamos, New Mexico 87545
FTS 843-6014

Goals: The overall objective of this program is to contribute to the development of practical thermochemical cycles for the production of hydrogen from water using primary heat sources.

Status: The principal program tasks are:

1.0 Experimental: Studies are being conducted to obtain accurate thermochemical data and practical kinetic data for key reactions in cycles that match the heat delivery characteristics of different heat sources. Currently, reactions for the formation and decomposition of bismuth oxysulfates are being studied as steps that minimize heat requirements for solution concentration in sulfuric acid cycles designed to couple with solar heat sources. Studies in a solids decomposition facility consisting of a rotary kiln have shown that $\text{Bi}_2\text{O}(\text{SO}_4)_2$ will decompose in less than 2 minutes at temperatures ranging from 973 to 1143 K. Activities for FY-81 will consist of additional bismuth oxysulfate decomposition experiments and studies of bismuth oxysulfate reactions with sulfuric acid at different temperatures and acid strengths. Design studies will be initiated to determine the suitability of different solids decomposition systems for solar heat input.

2.0 Process Evaluation: Technoeconomics studies have been conducted to determine differences in estimated capital costs and efficiencies between water electrolysis and thermochemical cycles as paths for hydrogen production from primary heat sources. The differences found were relatively minor and within estimation error. The final best method will depend on technical advances made in both branches of technology.

3.0 I.E.A. Information Exchange: As a continuing activity reports and papers are exchanged between U.S. Laboratories and other countries participating in Annex I. of the I.E.A. Agreement on Hydrogen Production. The fourth Annex I workshop is tentatively scheduled to be held in Julich, Germany, during the summer of 1981.

Contract No.: AL-10-05-15

Contract Period: FY-1980 **Funding Level:** \$225K

Funding Source: Department of Energy/Advanced Conservation Technologies

PROJECT SUMMARY

Project Title: Sulfur Cycle Hydrogen Production Process

Project Manager: G. H. Parker

Principal Investigator: P. W. T. Lu

Organization: Westinghouse Electric Corporation
Advanced Energy Systems Division
Post Office Box 10864
Pittsburgh, Pa. 15236

Project Goals: Major objectives include (1) providing a foundation for the long term development of efficient, long life and inexpensive electrolyzers for the hybrid electrochemical/thermochemical sulfur cycle, and (2) increasing the understanding of the electrochemistry of depolarized anode electrolysis in sulfurous/sulfuric acid solutions. Work toward these goals constitutes a portion of the overall development of the sulfur cycle. A complimentary program on the thermochemical aspects of the process is funded separately by DOE/Solar Energy.

Project Status: A series of tests has been performed with experimental electrolysis cells using various platinum catalyzed carbon electrodes. Major improvements in cell performance have been attained as indicated by measured cell voltages. When operated at 200 mA/cm² current density using 50 w/o acid at 50°C and 1 atm, a reference cell required 1.22 volts and degraded rapidly. After several improvements had been incorporated into electrodes and the test cell configuration, a later cell required only 0.77 volts under identical operating conditions. This cell exhibited stable operation with no measurable performance degradation. At a lower current density, 100 mA/cm², the cell required only 0.63 volts.

A one-week endurance test has been conducted with an intermediate cell operated at a 100 mA/cm² for 173 hours. This cell exhibited a stable voltage of 0.675 volts with no degradation after the first 80 hours.

Experiments have been made on two key gas separator figures of merit: diffusivity for sulfur dioxide-containing species and ionic resistivity. From diffusivity experiments several materials have been identified that have diffusion coefficients substantially lower than the reference material, microporous rubber. A cation exchange membrane material, P-4010, has exhibited an excellent diffusion coefficient, more than two orders of magnitude lower than that of rubber.

Current efforts are emphasizing reduction of precious metal loadings on the electrodes without compromising cell performance. Initial tests have indicated that cells with cathodes loaded with 2 mg/cm² of platinum on carbon substrates perform as well as earlier cells that used 10 mg/cm². A long term goal is to achieve loadings less than 0.5 mg/cm² on both cathodes and anodes.

Contract Number: JPL 955380 DE-AC02-80ET25208

Contract Period: February 79 - May 1980 -
February 80 December 1980

Funding Level: \$251K \$118K

Funding Source: DOE/STOR via JPL DOE/STOR via BHO

PROJECT SUMMARY

Project Title: Studies on Thermochemical Water-Splitting Cycles

Principal Investigators: R. J. Remick, S. E. Foh

Organization: Institute of Gas Technology
3424 South State Street
Chicago, Illinois 60616
(312) 567-3929

Project Goals: The purpose of this program was to assess the electrochemical oxidation of sulfur dioxide in relatively dilute (less than 50 weight percent) sulfuric acid and to determine the preferred operating conditions (acid concentration, temperature, electrode materials) for such a cell to be mated with a metal oxide-metal sulfate water-splitting cycle. Based on extensive thermodynamic evaluations of hybrid water-splitting cycles, we estimate that total cell voltages of 0.5 V or less are desired to compete with electrolytic water-splitting. Electrochemical kinetics (current density) will have a direct bearing on system cost. We estimate that current densities of about 200 mA/cm² or more are required for a practical cell, although this value is strongly dependent on the cost of electrode materials. Therefore, our rough performance goals were 200 mA/cm² at 0.5 V.

Project Status: This phase of the project has been completed.

Contract Number: 955494

Contract Period: June 1979 - June 1980

Funding Level: \$75,000

Funding Source: Jet Propulsion Laboratory

PROJECT SUMMARY

Project Title: Thermochemical Hydrogen Production Management

Principal Investigator: Christopher England

Organization: Jet Propulsion Laboratory
4800 Oak Grove Drive
Mail Stop 507/207
Pasadena, California 91103
(213) 577-9060

Project Goals: This activity monitors technical progress and problems in the program for the production of hydrogen by thermochemical cycles. Analyses of process costs, process chemistry and process thermodynamics are conducted in conjunction with the technical monitoring of DOE funded activities at industrial, academic and national laboratories.

Project Status: Continued development of the two major cycles showed good progress with the possibility of both being economically viable in light of new cost projections for synfuels. The major concern is for the relatively slow progress in developing an electrolyzer for the hybrid cycle. IGT, under JPL contract, extended earlier German work to an electrolyzer with potentially dramatic improvement of performance. Development of this concept to an operating electrolyzer is planned for this year. Progress on the sulfur/iodine cycle has been excellent in view of the level of support. The major economic and thermodynamic problem rests primarily on reducing water inventory within the cycle.

New Cycles have been proposed this year, but seem not competitive with those under development, primarily for engineering reasons.

Contract Number: ET-78-1-01-3112 (One of several tasks)

Contract Period: FY'80

Funding Level: \$195K (FY'80) (For all tasks under IA ET-78-1-01-3112)

Funding Source: DOE-STOR

MATERIALS AND STORAGE SYSTEMS

PROJECT SUMMARY

Project Title: Optical and Electrocatalytic Investigations of Oxides of Ruthenium and Iridium

Principal Investigator: Fred H. Pollak

Organization: Brooklyn College, CUNY
Physics Department
Bedford Avenue and Avenue H
Brooklyn, N.Y. 11210
(212) 780-5356

Project Goals: The objectives of this study are to (1) correlate optical measurements of oxide film characteristics with electrocatalytic activity and (2) determine the dependence of electrocatalytic activity on crystal orientation.

Project Status: (1a) We have measured the near-normal incidence reflectivity spectrum of single crystal IrO_2 and RuO_2 with light polarized perpendicular and parallel to the c-axis in the range 0.5-9eV. This study has enabled us to obtain the optical constants of this material.

Since peak positions in ϵ_2 , the complex dielectric constant, and the joint density of states agree, we have been able to verify experimentally the correctness of assumptions concerning the nature of the bonds in these materials. Experimental results for IrO_2 compare well to the band structure and density of states calculation of Mattheiss. We are thus able to confirm, in detail, the nature of the oxygen p and Ir d-electronic states. Preliminary optical measurements of RuO_2 are complete.

These results will provide important information in the investigation of the correlation of optical measurements of oxide film characteristics with electrocatalytic activity.

(1b) Tasks for FY 1980

1. Growth of larger crystals of RuO_2 and IrO_2 .
2. Detailed kinetic and mechanistic studies of oxygen evolution on these single crystal surfaces using rotating disc techniques.
3. Combined electrochemical optical studies on these single crystals and on oxidized metals to determine the intrinsic source of the catalytic activity of these materials.

Contract No.: EC-77-S-02-4590

Contract Period: May 1980 - September 1981

Funding Level: \$30,000.

Funding Source: Department of Energy

PROJECT SUMMARY

Project Title: Ammonia as a Hydrogen Energy-Storage Medium

Principal Investigator: G. Strickland

Organization: Brookhaven National Laboratory
Bldg. 120
Upton, New York 11973
(516) 345-4091

Project Goals: To develop safe and economic hydrogen energy-storage systems based on the storage and cracking of ammonia.

Project Status: This work is a new effort in the search for alternate methods of storing hydrogen. A preliminary review has shown that ammonia is substantially superior to liquid hydrogen and methanol in energy input for ammonia manufacture from natural gas, in hydrogen energy content of the medium, and in energy cost (\$/10⁶ Btu). Five main tasks were established. Further review is planned prior to initiating the experimental work.

Contract No.: DE-AC02-76CH00016

Contract Period: October 1, 1979 - September 30, 1980

Funding Level: -

Funding Source: Brookhaven National Laboratory

PROJECT SUMMARY

Project Title: Microcavity Hydrogen Storage

Principal Investigator: Robert J. Teitel

Organization: Robert J. Teitel Associates
9145 Chesapeake Drive
P.O. Box 81921
San Diego, California 92138
(714) 565-6441

Project Goals: The goals of the Microcavity Hydrogen Storage program FY 80 is: to prepare a two cu. ft. bed of filled microspheres for BNL tests; to establish standard procedures for characterizing testing microsphere beds; to experimentally test eight commercial grades; to select two grades for further study; to apply treatments to the two selected grades of microspheres to improve their properties; to subject specimens of the two selected grades to cyclic fill and dispense tests; to estimate a projected cost of microspheres and estimated storage costs.

Project Status: Attempts to fill larger microsphere beds was started in FY 79 but were frustrated by the procurement of suitable microspheres and the availability of facilities. This year, RJTA built a facility and delivered a two cu. ft. bed of filled microspheres to BNL. Test procedures were standardized and eight commercial grades were tested. As a result of the screening tests, it has been established that microspheres strong enough to withstand a 6000 psig, nitrogen, hydrogen and helium atmospheres. Less breakage loss was observed for hydrogen and helium than for nitrogen. Two of the most promising microspheres will be selected for further study. An optimization study for the two microsphere grades was initiated and cyclic fill-dispense tests planned for FY 81. Projected microsphere costs were estimated and storage cost information updated.

Contract Number.: BNL 511197-S

Contract Period: March 17, 1980-March 16, 1981

Funding Level: \$125,000 FY 80
\$ 56,000 FY 81

Funding Source: Brookhaven National Laboratory

PROJECT SUMMARY

Project Title: Modification and Operation of the Hydrogen Homestead Hydride Vessel Energy Storage System

Principal investigator: Roger E. Billings

Organization: Billings Energy Corporation
Hydride Research Division
18600 East 37th Terrace South
Independence, Missouri 64057
(816) 373-0000

Project Goals: The purpose of this research program is threefold
First: To study the performance of large hydride vessel in the release of stored hydrogen at specified demand levels. Second: To determine the energy needs of the hydrogen homestead(s) and the ability of the vessel to satisfy those needs. Third: To study the safety needs of such a storage system in relation to the hydrogen homestead(s).

Project Status: The tasks specified under this contract include the modification of the existing hydrogen flow and monitoring systems, the actual monitoring of the system under operating conditions, data reduction and graphical interpretation of the resultant data, and the installation and detailed description of the required safety system. A complete description of the energy consumption associated with the homestead(s) is also acquired. Accomplishments to date include the completed design and installation of the specified hydrogen flow system, including the molecular sieve dryers which prevent poisoning of the metal hydrogen and the design and installation of the required safety system. Data acquisition has been begun with the initial charge of the hydride vessel. The energy consumption analysis associated with the hydrogen homestead(s) has also been completed.

Remaining tasks include the acquisition and reduction of experimental data into graphical and tabular form.

Contract Number: BNL 48147-S

Contract Period: May 1, 1979 - October 31, 1980

Funding Level: \$60,000

Funding Source: Brookhaven National Laboratory

PROJECT SUMMARY

Project Title: Hydrogen Microsphere Safety Study

Principal Investigator: R. G. Zalosh

Organization: Factory Mutual Research Corporation
1151 Boston-Providence Turnpike
Norwood, Massachusetts 02062

Project Goals: The objective of the program is to perform a preliminary hazard evaluation of hydrogen storage and transport in hollow glass microspheres. Flammability, explosibility, and miscellaneous hazards of hydrogen filled microspheres are being assessed by laboratory testing, review of pertinent safety standards and regulations, and an analysis of potential accident scenarios. Microsphere hazards will be compared to the hazards of the other hydrogen storage modes: metal hydrides, liquid hydrogen, and compressed gas.

Project Status: Laboratory tests have been completed. Results are now being analyzed and compared to the equivalent data for metal hydrides, gaseous and liquid hydrogen. Pertinent safety codes and regulations have also been evaluated will be a preliminary analysis of the hazards of alternative packaging forms being considered for hydrogen filled microspheres.

Contract No.: Prime: DE-A202-76CH00016
Sub: BNL-510190-S

Contract Period: March 1980 - January 1981

Funding Level: \$28,094

Funding Source: Department of Energy/Brookhaven National Laboratory

PROJECT SUMMARY

Project Title: Hydrogen Microsphere Safety Study
Principal Investigator: R. G. Zalosh
Organization: Factory Mutual Research Corporation
1151 Boston-Providence Turnpike
Norwood, Massachusetts 02062

Project Goals: The objective of the program is to perform a preliminary hazard evaluation of hydrogen storage and transport in hollow glass microspheres. Flammability, explosibility, and miscellaneous hazards of hydrogen filled microspheres are being assessed by laboratory testing, review of pertinent safety standards and regulations, and an analysis of potential accident scenarios. Microsphere hazards will be compared to the hazards of the other hydrogen storage modes: metal hydrides, liquid hydrogen, and compressed gas.

Project Status: Laboratory tests have been completed. Results are now being analyzed and compared to the equivalent data for metal hydrides, gaseous and liquid hydrogen. Pertinent safety codes and regulations have also been reviewed briefly. A key issue remaining to be evaluated will be a preliminary analysis of the hazards of alternative packaging forms being considered for hydrogen filled microspheres.

Contract No.: Prime: DE-AC02-76CH00016,
Sub: BNL-510190-S

Contract Period: March 1980 - January 1981

Funding Level: \$28,094

Funding Source: Department of Energy/Brookhaven National Laboratory

PROJECT SUMMARY

Project Title: Hydrogen Containment Materials

Principal Investigator: Dr. Howard G. Nelson

Organization: NASA-Ames Research Center
Materials Science and Applications Office/230-4
Moffett Field, CA 94035
FTS 448-6137, (415) 965-6137

Project Goals: The containment materials program had the overall objective of helping to develop the understanding required for the economic, safe, long-term containment of hydrogen. Specifically, through the use of model environments, existing low cost materials, having intermediate to long-term hydrogen compatibility, were to be identified; new, inexpensive, and highly compatible alloys were to be developed; and reliable accelerated testing techniques and life prediction methods were to be established. The program contained both fundamental and applied elements including an experimental pipeline-loop on which service experience was to be gained.

Project Status: Although the containment materials program has had a relatively short life, a significant increase in our understanding of hydrogen degradation of carbon and low-alloy containment steels has been attained. Probably the most significant finding is that these containment steels can be severely degraded by the presence of hydrogen, but, in a manner considerably different than that observed for the extensively studied, higher strength, martensitic steels. Our findings indicate that the primary mechanism of hydrogen degradation in low strength steels is different than in the high-strength steels, and, therefore, much of the information available on degradation of high-strength steels does not appear to be applicable to the behavior of low strength steels in hydrogen.

Tasks being terminated are Thermal Processing Task, \$60K, NASA-Ames; Effect of Stress State on Hydrogen Embrittlement, \$45K, Virginia Polytechnic Institute; Near Threshold Fatigue Crack Propagation in Pipeline Steels in High-Pressure Environments, \$75K, Rockwell International Science Center; and Hydrogen and Fatigue Properties of Steel, \$45K, Cornell University, as well as an oversight function of Hydrogen Compatibility of Structural Materials for Energy Storage and Transmission, Sandia Laboratories, Livermore.

Contract Number: ET-78-1-01-3112

Contract Period: FY80

Funding Level: \$225K

Funding Source: Department of Energy-STOR

PROJECT SUMMARY

Project Title: Study of the Behavior of Gas Distribution Equipment
in Hydrogen Service - Phase II

Principal Investigator: Walter J. Jasionowski

Organization: Institute of Gas Technology
IIT Center
3424 South State Street
Chicago, Illinois 60616
(312) 567-3650

Project Goals: The main objective of this program is to identify operating, safety, and materials problems associated with the use of hydrogen in conventional gas distribution systems. Phase II was designed to determine permeabilities of commercial plastic gas distribution piping for hydrogen and methane, and leakage characteristics for mixtures of the two gases. The results, along with A.G.A. data, permitted an assessment of the U.S. distribution system's overall (hypothetical) permeation and leakage losses for different combinations of natural gas and hydrogen.

Project Status: The work on this program was completed. Permeability determinations were made for eleven samples of commercially available polyethylene pipe, using project-designed permeability cells and test loops. Ring tensile tests were also performed to compare as-received and permeability-exposed piping. The residential/commercial test loop was modified to serve in leakage experiments with varying hydrogen-methane mixtures. Extrapolating from these results, the total possible permeation and leakage losses in the U.S. distribution system were assessed.

Contract Number: JPL No. 955447

Contract Period: April 26, 1979 - June 26, 1980

Funding Level: \$95,033

Funding Source: Jet Propulsion Laboratory

MECHANICAL, MAGNETIC, AND UNDERGROUND ENERGY STORAGE

INTRODUCTION

Within this activity, six energy storage technologies are being developed: Flywheels, Compressed Air, Underground Pumped Hydroelectric, Seasonal Thermal Energy Storage, and Superconducting Magnetic Energy Storage.

The major near-term objective of the flywheel project is to provide safe and economical storage systems for electric hybrids, ICE vehicles and pulsed industrial drives. This activity concentrates on developing composite rotors, advanced bearings, rotating shaft seals and vacuum pump equipment. The energy storage capacity of a flywheel is practically limited by its strength. Where system weight must also be limited, a high strength-to-density ratio is essential; composite materials, such as fiber filaments bonded by epoxy, satisfy this requirement. Energy storage capacity is also influenced by rotor cross-discs, cylinder, concentric rings and thin rims.

Compressed Air Energy Storage is directed at near-term electric utility load leveling applications. Off-peak electrical power would operate compressors delivering air to storage within an artificial salt cavern, hard rock cavern or porous subterranean medium. Two designs have been suggested: isothermal and adiabatic. In the isothermal design, the heat of compression is rejected to the atmosphere and must be replaced during expansion by combustion of fossil fuel. In the adiabatic design, the heat of compression is removed and stored for later reinjection into the air stream prior to expansion through a turbine. The compressed air may be stored at constant volume or constant pressure. The latter scheme uses hydraulic compensation and requires a lesser total volume.

Underground Pumped Hydroelectric Storage is another alternative to the gas turbine for load leveling and peak shaving. During off-peak hours water is pumped from an underground lower reservoir excavated from hard rock to a natural or artificial surface reservoir. During peak power demand the water flows down the penstock shaft turning a water turbine and electrical generator. Off-peak energy for pumping is generated by base-load coal or nuclear fueled plants.

The Seasonal Thermal Energy Storage Program is designed to demonstrate the economic storage and retrieval of energy on a seasonal basis, using heat or cold available from waste sources or other sources during a surplus period to reduce peak period demand, reduce electric utilities peaking problems, and contribute to the establishment of favorable economics for district heating and cooling systems for commercialization of the technology. Aquifers, ponds, earth, and lakes have potential for seasonal storage. The initial thrust of this program is toward utilization of groundwater systems (aquifer) for thermal energy storage.

The program has the further objective of evaluating other methods of seasonal storage, both from existing literature and by following current work in other countries. New program thrusts may be recommended as a result of these studies.

Superconducting Magnetic Energy Storage (SMES) is directed at electric utility leveling applications. Two potential benefits may be realized: (1) reduction of dependence upon peaking generators, and (2) increase in the capacity of transmission lines by damping out oscillations in the lines. At present, a 10 kWh stabilization system will raise capacity of a transmission

line from 2,400 MW to 3,000 MW. In the longer term, storage sizes for peaking utilization will range from 1,000 to 10,000 MWh. Off-peak power would be delivered to a superconducting electromagnet emplaced in bedrock. The computed efficiency of energy recovery from SMES is 85 to 90%. The magnet necessary for practical storage would be about 1,100 meters in diameter, 11 meters high, and about 5 meters thick. The technology necessary to reach demonstration has not yet been developed.

The principal contacts for these activities at DOE Headquarters are:

- | | |
|------------------|--|
| Brian Gallagher | - Compressed Air Energy Storage
Seasonal Thermal Energy Storage
Underground Pumped Hydroelectric |
| Eberhart Reimers | - Flywheels |
| Saul Strauch | - Superconducting Magnetic Energy Storage |

The principal contacts for these activities at field organizations are:

- | | |
|--|---|
| Thomas Barlow
Lawrence Livermore National
Laboratory | - Flywheels for Vehicles |
| Landis Kannberg
Pacific Northwest Laboratory | - Compressed Air Energy Storage
Underground Pumped Hydroelectric |
| James Minor
Pacific Northwest Laboratory | - Seasonal Thermal Energy Storage |
| John Rogers
Los Alamos Scientific Laboratory | - Superconducting Magnetic Energy Storage |

FLYWHEEL ENERGY STORAGE

PROJECT SUMMARY

Project Title: Mechanical Energy Storage Technology Project

Principal Investigator: Thomas M. Barlow

Organization: Lawrence Livermore National Laboratory
P.O. Box 808, Mail Stop L-388
Livermore, CA 94550; Phone: (415)-422-8200

Project Goals: The goals of this project are to develop, demonstrate, and evaluate mechanical energy storage technology for vehicular and fixed-base applications and to carry out the R, D&D activities in a manner that maximizes the commercialization potential of the technology.

Project Status: The Lawrence Livermore National Laboratory's efforts were initiated in FY1975. Initially, these involved the development and characterization of fiber-composite materials for use in high performance flywheels. Late in FY1977 and FY1978, respectively, the project expanded to include development of MEST technology for application to electric and hybrid vehicles and evaluation of the laminated disc rotor concept. Funding in the former area was provided under the Electric and Hybrid Vehicle RD&D Act of 1976 (Public Law 94-413). In FY1980, the project was again expanded to include the technical management responsibility for flywheel rotor and mechanical component technology development as well as the evaluation of fixed-base applications of flywheel systems.

Milestones achieved in FY1980 included:

- Completion of tests of prototype flywheel units for electric vehicle application.
- Initiation of design for heat engine/flywheel vehicle.
- Completion of tests of advanced flywheel rotor concepts.
- Evaluation of flywheel rotor containment concepts.
- Qualification of an independent rotor test facility.
- Initiation of a multi-year planning effort for the project.

The project currently consists of six tasks, listed below. The estimated FY1980 expenditure level for each task is included; these do not include efforts directly funded by DOE.

• Transportation Applications	\$ 97,000
• Fixed-Base Applications	250,000
• Fiber Composite Materials Characterization	370,000
• Flywheel Rotor Technology	1,250,000
• Advanced Component Technology	600,000
• Project Management and DOE Support	427,000

For the most part, the project's activities are carried out through subcontracts to private industry. In-house activities include technical management, material characterization, and tapered-thickness rotor concept evaluation.

Contract Number: W-7405-eng-48

Contract Period: Continuing

Funding Level: \$3,672,000 B/O - Energy Storage
\$ 195,000 B/O - Distributed Solar Technology

PROJECT SUMMARY

Project Title: Laboratory Development and Evaluation of a Regenerative Flywheel Energy Storage System

Principal Investigator: Edward P. Cornell

Organization: General Electric Company
Corporate Research and Development
Schenectady, New York 12301

Project Goals: Demonstrate new technology associated with a flywheel energy storage system comprised of a flywheel coupled directly to an a.c. synchronous motor/alternator and fed by a solid-state inverter/rectifier unit designed to provide the necessary frequency control from a constant d.c. voltage power supply. Determine electric vehicle range improvement that can be attributed to the use of a flywheel in combination with a lead-acid battery bank.

Project Status: The project has been completed.

A flywheel energy storage and recovery system for a battery/flywheel electric vehicle of the 3000-pound class was developed, fabricated, and laboratory tested. The vehicle propulsion system was simulated on a digital computer in order to determine the optimum system operating strategies and to establish a calculated range improvement over a non-regenerative, all electric vehicle. The flywheel energy storage system consists of a solid rotor, synchronous, inductor-type, flywheel drive machine electrically coupled to a d.c. battery electric propulsion system through a load commutated inverter. The motor/alternator unit is coupled mechanically to a small steel flywheel which provides a portion of the vehicle's accelerating energy and regenerates the vehicle's braking energy.

The energy recovery system operated successfully over the speed/torque/time profile of a 3000-pound vehicle operating repetitively on SAE J227a driving schedules. The maximum range obtained on the Schedule D cycle was 83.7 miles. This is estimated to be a 15% to 20% improvement in range over a regenerative, chopper-driver all-electric vehicle operating on the Schedule D driving cycle, and a 47% improvement over a non-regenerative all-electric vehicle on the same schedule.

Contract Number: W-7405-ENG-48, Subcontract 8990503

Contract Period: March 17, 1978, through June 30, 1980

Funding Level: \$544,624

Funding Source: U.S. Department of Energy through the Lawrence Livermore National Laboratory

PROJECT SUMMARY

Project Title: Flywheel-Engine Powerplant Research and Development Studies

Principal Investigators: Norman H. Beachley and Andrew A. Frank

Organization: College of Engineering
University of Wisconsin
Madison, Wisconsin 53706

Project Goals: The overall objective is to provide engineering design and analysis services leading to the construction of a flywheel/heat engine demonstration vehicle with the goal of demonstrating 50 mpg over the Federal Urban Driving Cycle (FUDC) at 3,000 lb. inertia weight.

Project Status: Several continuously-variable transmission (CVT) designs have been developed that are suitable for the demonstration vehicle with packaging worked out for the GM X-body front-wheel-drive chassis. The Eaton Corporation now has a contract that will lead to system hardware, and we are working with them to give them the benefit of our previous work and experience.

Specifications have been developed for the CVT characteristics required for satisfactory installation, performance, and control in the demonstration vehicle. CVT efficiency characteristics for this flywheel drive vehicle have been specified that will provide 50 mpg over the FUDC.

Simulations have been made of mileage of the demonstration vehicle over a number of driving cycles. A real-time hybrid (digital-analog) computer simulation has also been developed and used to study the shifting and control problems of the alternative CVT designs. Studies are underway to determine optimal flywheel size. It appears that an energy storage capacity of about 0.3 hp-hr. is adequate for a 3000-lb. inertia weight vehicle.

A "four-square" dynamometer has been constructed for testing CVT efficiency characteristics and control concepts. Tests are being conducted on the van Doorne steel V-belt system at present.

Preliminary designs for "active" flywheel protection have been developed in order to stop the flywheel rotation when failure is impending without imparting angular momentum reaction to the vehicle, and to automatically disengage the flywheel from the vehicle's drive train.

Contract Number: W-7405-ENG-48, Subcontract 4492309, Amend. 2

Contract Period: 1 January 1980 through 30 September 1980

Funding Level: \$90,000

Funding Source: U.S. Department of Energy through Lawrence Livermore National Laboratory

BEST DOCUMENT AVAILABLE

PROJECT SUMMARY

Project Title: Flywheel/Heat Engine Vehicle Design and Analysis

Principal Investigator: Ilmar Kalns

Organization: Eaton Corporation, Engineering & Research Center
P. O. Box 766, Southfield, MI 48037

Project Goals: Study concepts and design a Flywheel/Engine/CVT propulsion system suitable for installation in an X-body car.

Project Status: The project is about 1/3 completed. Its five principal tasks are: conceptualization of the system, definition of controls, testing and evaluation of a CVT, preliminary design of complete system, and simulation study of economy gains over conventional systems.

The selection of the system concept has been finalized through study and simulations of several potential schemes. The selected arrangement appears most likely to meet the economy and performance goals, as well as size and weight constraints.

Testing and evaluation of a potentially suitable CVT (Van Doorne's Transmatic) are in progress; initial indications are favorable. Preliminary layout of the propulsion system is expected to start shortly. Component size selection and packaging study of X-body car are nearing completion.

Simulation study of economy gains realized with the proposed system is to run concurrently with preliminary layout work.

Contract Number: Subcontract 9515409

Contract Period: 8/4/80 - 3/4/81

Funding Level: \$276,059

Funding Source: University of California
Lawrence Livermore Labs

PROJECT SUMMARY

Project Title: Regenerative Braking Through Elastomeric Energy Storage

Principal Investigator: Lyle O. Hoppie

Organization: Eaton Corporation
Engineering & Research Center
P. O. Box 766
26201 Northwestern Highway
Southfield, Michigan 48037

Project Goals: Determine the technical and economical feasibility of an elastomeric regenerative braking system (ERBS) for automotive applications.

Project Status: Phase II of this program was initiated in July 1979, and was subdivided into two major sections:

- Phase II-A was to cover the design, construction, laboratory testing and evaluation of full-size elastomeric energy storage units.
- Phase II-B was to cover the design, construction, laboratory testing and evaluation of a complete full-scale elastomeric regenerative braking system.

During Phase II-A, efforts were focused on multiple adjacent elastomeric rods stressed in torsion beyond the buckling limit such that "knots" were generated. The measured torque versus rotation characteristics were in good agreement with values predicted from empirical equations deduced during the Phase I testing of small-scale samples, and the measured round-trip efficiency of these full-size elastomeric energy storage units approached ninety percent. Due to the abrasion of adjacent elastomeric rods, however, the fatigue life of the full-size units was only a few thousand cycles, in general agreement with small-scale test results. The low fatigue life problem appears to have been solved by employing a different stressing scheme in which a single rod is axially preloaded prior to being placed in torsion; small-scale tests of this stressing scheme show fatigue lives in excess of 10^5 cycles.

The initial tasks of Phase II-B, initiated in June 1980, call for the evaluation of the new stressing scheme using molded full-size elastomeric energy storage units. If the test results are sufficiently encouraging, the balance of Phase II-B will be carried out.

Contract Number: University of California Subcontract 2617509

Contract Period: June 1980 - December 1980 for first part of Phase II-B

Funding Level: \$272,000 for first part of Phase II-B

Funding Source: U. S. Department of Energy through Lawrence Livermore Laboratory

PROJECT SUMMARY

Project Title: "A Flywheel Energy Storage and Conversion System for Photovoltaic Applications."

Principal Investigator: Philip O. Jarvinen

Organization: Massachusetts Institute of Technology
Lincoln Laboratory
Energy System Engineering Group
P.O. Box 73
Lexington, Massachusetts 02173
(617) 862-5500 ext. 213

Project Goals: To develop a flywheel system to store electrical output from a solar photovoltaic array and convert it to regulated 60-Hz AC for use in residences or load centers, and to analyze its performance, worth, and cost.

Project Status: A 1/10-scale model flywheel unit with a 400-pound rotor and storage capacity of 1 to 4 kWh has been built and tested over the full design speed range between 7500 to 15000 rpm. The unit consists of magnetic bearings, integrated motor-generator, motoring and power-conversion electronics, and vacuum and containment housing. Stand-alone cycloconverter and utility-interactive inverter power conditioners have been demonstrated experimentally which produce 120-V, 60-Hz AC with excellent power quality. Measured round-trip efficiencies of the stand-alone version of the flywheel storage system have exceeded 74 percent. Flywheel storage systems are the equal of or superior to battery systems for the same application.

Manufacturing cost studies and user-worth analyses for flywheel systems of residential and load-center sizes have been completed. Residential flywheel systems have been found to be economically viable in stand-alone and utility-interactive applications.

Contract Number: DE-AC02-76ET-20279

Contract Period: FY-80

Funding Level: \$605K

Funding Source: U.S. Department of Energy, jointly by Divisions of Energy Storage and Photovoltaic Energy Systems

PROJECT SUMMARY

Project Title: Development and Assessment of Stationary Flywheel Storage Technologies

Principal Investigator: David B. Eisenhaure

Organization: The Charles Stark Draper Laboratory, Inc.
555 Technology Square
Cambridge, Massachusetts 02139

Project Goals: Assessment of flywheel storage technology and application coupled with developments in the bearing and power conditioning areas.

Project Status: The project is in progress and consists of the following elements:

- a) Systems analysis directed toward assessing the status and worth of stationary flywheel storage.
- b) Experimental investigation of magnetic bearing concepts and systems.
- c) Development of a MOSFET based power conversion system for flywheel applications.
- d) Investigation of field-modulated machines for flywheel applications.
- e) Development of advanced hybrid ball/magnetic bearings and lubrication systems.

Work in the assessment area is currently directed toward assessing the worth of flywheels with current technology and with today's energy costs. Experimental investigations have indicated a number of areas where the performance of flywheel systems can be enhanced through technology improvements.

Contract Number: Subcontract 9385809

Contract Period: May 27, 1980, through September 30, 1980

Funding Level: \$44,095

Funding Source: U.S. Department of Energy through Lawrence Livermore Laboratory, and Corporate Research Funds

PROJECT SUMMARY

Project Title: Continued Development of the Band-Type Variable Inertia Flywheel

Principal Investigator: David G. Ullman

Organization: Union College
Department of Mechanical Engineering
Schenectady, N. Y. 12308

Project Goals: To determine whether or not the band-type variable inertia flywheel (BVIF) concept is a competitive energy storage and transmission device.

Project Status: The project has been completed. The following was shown:

1. The Band-Type Variable Inertia Flywheel (BVIF) is a system capable of storing and delivering energy in usable form. This is a single mechanism, which, unlike conventional flywheels, does not require any intermediate transmission equipment. A BVIF has been built and operated which is capable of smoothly accelerating a directly-connected inertial load from rest to a final speed without significant clutch-slipping losses or any additional transmission devices.
2. There are essentially three ways to attach loads to a BVIF. The first is an open-loop system with two degrees of freedom, referred to as the Type I. The second (Type II) is a single-degree-of-freedom unit with a fixed ratio between hub speed and casing speed. The third (Type III) has two degrees of freedom like Type I but includes power recirculation through a gear train like Type II. Of these, the Type III has been identified as the most promising configuration.
3. The Type III BVIF is capable of accelerating inertial loads smoothly and with stability to a terminal speed. That final speed can be greater than the initial flywheel speed, and both inner and outer elements of the BVIF slow down. The Type III BVIF is capable of yielding more than half of its stored energy to the load during such an operation.
4. Prototype testing in the Type III mode has produced real-world evidence of Type III BVIF capacity. Further work remains to be done to fully characterize the nature of such systems.
5. Subsequent efforts have shown that the Type III system can be built with energy densities greater than 10 watt hr/lb for both the energy storage and transmission systems.

Subcontract Number: 6186109

Contract Period: July 1, 1979 - July 1, 1980

Funding Level: \$29,700.00

Funding Source: Lawrence Livermore Laboratories

PROJECT SUMMARY

Project Title: Cellulosic Flywheels: Material Design Properties

Principal Investigator: Arthur G. Erdman

Organization: Mechanical Engineering
University of Minnesota
Minneapolis, Minnesota 55455

Project Goals: Accurately evaluate critical material properties of hexagonal, birch plywood for use in evacuated rotors. Study further the costs and designs of cellulosic materials for rotors.

Project Status: A new high resolution rapid tensile testing method incorporating digital integrated acoustic emission measurements has been developed to evaluate the long term strength of viscoelastic composite materials using short term tests. This involved assembling a very precise, rapid data acquisition system, with detailed evaluation, analysis, and graphical display of the data derivatives and integrals and their correlations. The useable strength of hexagonal birch plywood has been estimated using this method which also appears applicable to synthetic composite materials. These evaluations are correlated with detailed measurements of the statistical distribution of the tensile strength to density ratio of vacuum-dried and 10% moist hexagonal birch plywood. Fracture toughness, fatigue, and duration of load tests are also being done. Preliminary measurements have been made of the vacuum drying rates of plywood disks and cylinders to evaluate the time and cost involved in this. The major conclusions are:

- a) The major effects of vacuum drying plywood have been evaluated and its strength and density distribution statistically evaluated. Hexagonal birch plywood can therefore be reasonably designed in moderate performance, low cost flywheels.
- b) Economic considerations suggest that hexagonal plywood is best suited for rotor cores around which to wrap higher performance materials. Highly oriented paper appears potentially competitive with other rotor materials for low cost stationary rotors.

It is recommended that further work be addressed to assembling compound rotors of high performance filament and ribbon materials wrapped around shaped plywood cores. Particular attention should be given to the potential of high performance paper.

Contract Number: W-705-ENG-48, Subcontract: 7551709

Contract Period: December 6, 1979, through December 5, 1980

Funding Level: \$48,480

Funding Source: U.S. Department of Energy through Lawrence Livermore Laboratories

PROJECT SUMMARY

Project Title: Laminated Composite Disc Flywheel Development

Principal Investigator: Ronald P. Nimmer

Organization: General Electric Company
Corporate Research and Development
Schenectady, New York 12301

Project Goals: Analytically and experimentally investigate the potential energy densities achievable with a design concept using a laminated central disc and a filament wound outer ring. Design and build a prototype flywheel rotor for tests to be conducted at Oak Ridge National Laboratory.

Project Status: All project tasks have been completed. The work can be considered as having two phases.

Based upon initial tests and design optimization, two hybrid disc-ring flywheels were designed and assembled with an interference fit in phase one. Subsequent burst tests of these flywheels at the Johns Hopkins Applied Physics Laboratory resulted in maximum energy densities of 57 Wh/kg (26 Wh/lb.) and 54 Wh/kg (24.5 Wh/lb.).

In phase two, two larger prototype flywheels were designed, fabricated and delivered for testing at Oak Ridge National Laboratory. Extensive supportive testing was conducted for effective design. These tests included ultrasonic modulus and damage definition, tensile tests, and fiber volume and void content measurements. Dynamic analyses and tests reflect a stiff flywheel rotor with little observed effect upon critical speeds due to the elastomeric bond. A burst speed in the vicinity of 66 Wh/kg (30 Wh/lb.) may be approached. Initial fatigue analyses indicate that energy densities of 33 Wh/kg to 44 Wh/kg (15 - 20 Wh/lb.) may be attainable at operating speeds.

Major recommendations are:

1. Scatter in material test data and possible "size effect" on material strength should be considered in the design.
2. Alternate matrix for the graphite/epoxy outer ring should be investigated for improved radial strength.
3. Variable winding tension should be used in programmed winding of flywheel rings to avoid residual stresses.
4. Test results at one facility on both thick and thin laminates are needed to determine how large an effect the laminate thickness has on maximum performance
5. Additional fatigue work is necessary.

Contract Number: Lawrence Livermore Laboratory Subcontract No. 2479309

Contracting Period: Fiscal year 1980

Funding Level: \$127,881

Funding Source: U. S. Department of Energy/Lawrence Livermore Laboratory

PROJECT SUMMARY

Project Title: Evaluation of Composite Flywheel Materials Construction

Principal Investigator: Alan D. Sapowith

Organization: Avco Systems Division
201 Lowell Street
Wilmington, Massachusetts 01887

Project Goals: Evaluate the specific energy density capability of bi-directional woven flywheel materials.

Project Status: The initial evaluation effort has been completed. A follow-on effort to improve material performance has been initiated.

Bi-directional (radial and circumferential) woven flywheel materials (S Fiberglass) were fabricated and molded into thin discs. Tensile tests were run to determine stiffness and strength of the material as a function of radial location and orientation. These data were used with Avco's WHEEL code to compute the maximum specific energy capability of these materials and the failure mode and location.

Test data and analyses show that specific energy densities of 28 Wh/lb are representative of the materials fabricated. It is interesting to note that while measured hoop strengths were well above 100,000 psi and radial strengths approximately 20,000 psi, the mode of failure was in the hoop direction, primarily at the inside and outside radii. This is the result of the inertial loads in the system.

Contract Number: Subcontract 6692009

Contract Period: August 1979 through August 1980

Funding Level: \$34,999

Funding Source: U.S. Department of Energy through Lawrence Livermore Laboratories

PROJECT SUMMARY

Project Title: Flywheel Technology Development at APL

Principal Investigator: David W. Rabenhorst

Organization: The Johns Hopkins University
Applied Physics Laboratory

Project Goals:

1. Define improvements to existing flywheel spin test facility which will permit testing flywheels up to 50 kilowatt-hours capacity.
2. Preliminary development of metallic glass ribbon flywheel.
3. Spin tests of various flywheels as directed by Lawrence Livermore Laboratory.

Project Status:

1. A 5 kilowatt-hour spin test facility was defined having a capability of testing flywheels up to 200 pounds at rotational speeds up to 60,000 rpm. A 50 kilowatt-hour spin test facility was defined having a capability of testing flywheels up to 4000 pounds at rotational speeds up to 18,000 rpm. Spin tests have demonstrated the feasibility of low cost metallic glass ribbon flywheels at energy densities of 12 to 24 wh/lb and 5000 to 10,000 wh/ft³.
2. Feasibility has been demonstrated of recording television pictures at a rate up to 960 frames per second.
3. A number of Lawrence Livermore Laboratory furnished flywheels have been successfully spin tested.

Contract Number: W-7405-ENG-48, Subcontract 7825509

Contract Period: 21 March 1980 through 31 December 1980

Funding Level:

Section 1 - Flywheel Test Facility	\$157,400
Section 2 - METGLAS Flywheel	\$50,000
Section 3 - Flywheel Testing	\$71,800

Funding Source: U.S. Department of Energy through the Lawrence Livermore Laboratory

PROJECT SUMMARY

Project Title: Tapered Thickness Composite Laminate Flywheel Rotor Development Program

Principal Investigator: Satish V. Kulkarni

Organization: Lawrence Livermore National Laboratory
P.O. Box 808, L-338,
Livermore, CA 94550
Telephone: (415)-422-7128; FTS 532-7128

Project Goals: 1) Prototype development of a tapered thickness composite laminate flywheel rotor; 2) Development of a bonded attachment technique for multiple discs and generation of design data for the rotor/hub elastomeric bond; and 3) Nondestructive inspection of various prototype composite rotors.

Project Status: Four 24 in. diameter, tapered thickness composite laminate rotors (two S2-glass/epoxy and two graphite/epoxy) were fabricated. These rotors utilized the matched metal die compression molding process for laminate fabrication and incorporated the edge thickening concept to increase energy density and a modified layup pattern to reduce strength anisotropy. One 15 in. diameter, constant thickness S2-glass/epoxy rotor was spin tested at APL and yielded an energy density of 30.4 wh/lb at burst. Finite element studies were conducted to optimize chopped fiber molded disc/filament wound rim hybrid rotor configurations. A biaxial stress test fixture was also designed and fabricated and is being assembled presently.

A rotor/hub bonding technique which employs polyurethane instead of natural rubber and adhesives has been developed. Static/fatigue design data for this elastomeric interlayer are being generated. Analytical and fabrication feasibility studies for the bonded attachment techniques for multiple discs have been initiated.

Nondestructive evaluation of the six prototype rotors (Garrett, Brobeck, Rocketdyne, Hercules, GE, and LLNL) was performed prior to spin testing at Y-12, Oak Ridge. Both ultrasonic and radiographic techniques were employed.

Contract Number: W-7405-ENG-48

Contract Period: October 1, 1979, through September 30, 1980

Funding Level: \$318,000

Funding Source: U.S. Department of Energy

(Mr. Kulkarni's paper was not prepared for the proceedings.)

PROJECT SUMMARY

Project Title: Low-Cost Compression Molded Fiber Reinforced Flywheels

Principal Investigator: Dr. John F. Kay

Organization: Owens-Corning Fiberglas
Research and Development Division
Technical Center
Granville, Ohio 43023

Project Goals: To fabricate low-cost, medium-performance flywheel rotors using the compression molding process.

Project Status: Two rotor shapes are being considered: a constant one-inch thickness disc and a tapered Stodola profile. Two reinforcing glass fibers, E glass and S-2 Glass, are being employed in one- and two-inch chop length.

Preliminary work on constant thickness moldings indicates that compression molding is a viable process for producing flywheel rotors in a low-cost, high-throughput fashion suitable for automotive applications.

The variables to be addressed in future work are the SMC charge configuration, molding time, molding temperature, molding pressure, and flow control to maintain optimal reinforcement positioning. Molding of tapered thickness discs must also be addressed.

Contract Number: (P.O. #9093009)

Contract Period: June 24-September 30, 1980

Funding Level: \$44,700

Funding Source: U.S. Department of Energy through Lawrence Livermore National Laboratories

PROJECT SUMMARY

Project Title: Fabrication of High Performance, Filament-Wound Fiber Composite Rings

Principal Investigator: Alan J. Hannibal

Organization: Lord Kinematics
1635 West 12th Street
Erie, Pennsylvania 16512
(814) 456-8511

Project Goals: Fabricate circumferentially wound fiber composite rings for General Electric's laminated disk flywheel program.

Project Status: The project has been completed. In all, sixteen (16) composite rings were fabricated on a computer controlled filament winding machine. Eleven (11) of these rings were made of graphite/epoxy and the remainder were made of Kevlar 49/epoxy. The rings had either an 11.0 inch or 14.5 inch inside diameter. They were 1.0 inch in axial thickness and ranged in annular thickness from 0.5 to 2.5 inches. The fabrication method was basically a wet winding process using a circumferential wrap of a fiber tow under tension onto a mandrel. To assure satisfactory quality and appearance, several process issues were addressed, including fiber tie-off, accommodation of the mandrel taper and outside surface finish.

One ring was wound directly onto a laminated composite disk. Although its appearance was good, the difference in thermal expansion and contraction between the ring and the laminated disk caused them to separate after the cure cycle.

During the term of the contract, several shortcomings in the composite rings were observed as a consequence of the winding process; namely, poor sidewall finish, the presence of residual stresses, nonuniform fiber fraction and void content in the radial direction, and relatively weak transverse strength. Most of these problems are being considered in an active subcontract with Lawrence Livermore Laboratories.

Contract Number: W-7405-ENG-48

Contract Period: 28 March 1979 through 11 July 1980

Funding Level: \$26,650.00

Funding Source: U.S. Department of Energy through General Electric

PROJECT SUMMARY

Project Title: State-of-the-Art Review of Flywheel Burst Containment

Principal Investigators: Alan D. Sapowith
Emmett A. Witmer

Organization: Avco Systems Division
201 Lowell Street
Wilmington, Massachusetts 01887

Project Goals: The project has been completed. A follow-on effort for a containment design has been initiated.

A review of burst containment as it applied to aircraft steel turbine rotors was made. Data from this review, while not conclusive, indicated that a containment ring of coiled cold rolled steel would be the most efficient design for composite flywheels. The limited data on woven dry Kevlar that indicated important weight savings for turbine blade containment could not be directly applied to containment of composite flywheels.

A containment design concept for disc-type flywheels was generated. Very light containment weights were projected for this design which took advantage of the apparent slow growth of composite disc flywheels at failure (burst) initiation.

Contract Number: Subcontract 6692009
First Amendment

Contract Period: November 1979 through May 1980

Funding Level: \$29,923

Funding Source: U.S. Department of Energy through Lawrence Livermore Laboratories

PROJECT SUMMARY

Project Title: Flywheel Containment Technology Assessment

Principal Investigators: Anthony P. Coppa, Carl H. Zweben

Organization: General Electric Company
Space Division
Box 8555, Philadelphia, Pa. 19101

Project Goals: Review and assess technology available for developing high performance, cost-effective containment housings for composite and metallic flywheels.

Project Status: The project has been completed and a report, entitled "Flywheel Containment Technology Assessment," has been issued. The major part of the assessment included the following topics: a) Physical features of the containment process; b) analytical methods; c) flywheel containment test methods and facilities; d) behavior of composite materials under impact loading; and e) composite flywheel failure behavior.

Metallic flywheels characteristically rupture in relatively large fragments which remain essentially intact during interaction with a containment housing. This results in relatively heavy containment requirements.

Composite rotors fail in a variety of modes depending on their detailed construction, and initial failure in some designs is accompanied by release of "hoop" type fragments which present lower damage hazards. Composite fragments, moreover tend to break up into smaller fragments during containment interaction and this transformation tends to reduce the damage potential. Hence, it appears that, in general, for an equal amount of stored energy, composite rotors require lighter containment

Design methods for reliably predicting initial and subsequent fragmentation for composite rotors and their effects on containment structures, however, do not exist at present. Efforts are now underway to develop such methods, as well as to gather together dynamic strength and other materials data that are required to implement them.

A significant conclusion resulting from the project is that the flywheel rotor and containment housing should be designed as a system in order to develop high performance systems.

Contract Number: W-7405-ENG-48, Subcontract 6624409

Contract Period: 21 August, 1979 through 20 November, 1979

Funding Level: \$45,027

Funding Source: U.S. Department of Energy through Lawrence Livermore Laboratories.

BEST DOCUMENT AVAILABLE

PROJECT SUMMARY

Project Title: Fiber Composite Materials Technology Development

Principal Investigator: T.T. Chiao

Organization: Lawrence Livermore National Laboratory
P.O. Box 808
Livermore, CA 94550

Project Goals: 1) To establish an energy data base on composites; 2) to evaluate new materials; 3) to study time-dependent behavior of composites; and 4) to provide materials information to industry.

Project Status: This is an ongoing project which covers three areas.

In the area of data base, the effect of vacuum and temperature on the Kevlar 49/epoxy composites was studied using unidirectional specimens. In new materials we concentrated on developing an epoxy matrix system for 120°C. For time-dependent behavior, we continued to study fatigue and creep at ambient temperature using Kevlar 49/epoxy strands.

A multi-year plan was outlined and reviewed with industrial and DOE representatives.

Major conclusions are as follows: 1) The effect of vacuum and temperature (10 to 30 Pa and 75°C) on the static properties of Kevlar 49/epoxy composites is limited to the transverse and shear moduli. This is primarily due to the temperature factor. A promising epoxy matrix which can be used for 120°C with low toxicity was developed for filament winding. We have disseminated all up-to-date information to industry by publishing timely short articles in Composites Technology Review.

It is recommended that the multi-year plan be put into practice starting FY-81.

Contract Number: W-7405-ENG-48

Contract Period: October 1, 1979, through September 30, 1980

Funding Level: \$434,000

Funding Source: U.S. Department of Energy through Lawrence Livermore National Laboratory

PROJECT SUMMARY

Project Title: Engineering Properties Determination for Fiber Composite Materials

Principal Investigator: H. Thomas Hahn

Organization: Washington University
Department of Mechanical Engineering
and Materials Research Laboratory
St. Louis, MO 63130

Project Goals: To develop design data base for a Kevlar 49/epoxy composite in simulated flywheel service environment.

Project Status: The project has been completed. Both static and fatigue properties of a Kevlar 49/epoxy have been characterized in the laboratory environment and also in vacuum at 75°C.

The epoxy, formulated at LLNL, was DER 332/Kelpoxy G293/Helox 68/Tonox 60-40(77/23/65/37.3) with a Tg of ~104°C. At 75°C both in air and in vacuum the longitudinal tensile strength was slightly higher than at the room temperature because of moisture desorption. The other strengths as well as the moduli showed only a small decrease.

The longitudinal fatigue properties in vacuum at 75°C were as good as those in the laboratory environment. The median fatigue strength at 10⁶ cycles was 70% of the average static strength. It is concluded that the composite can be used in vacuum at 75°C with only a minor loss in its mechanical properties.

Contract Number: W-7405-ENG-48; Subcontract 6641009

Contract Period: September 16, 1979, through September 15, 1980

Funding Level: \$50,835

Funding Source: U.S. Department of Energy through Lawrence Livermore National Laboratory

PROJECT SUMMARY

Project Title: Composite Flywheel Testing and Evaluation

Principal Investigator: Robert S. Steele, Jr., PhD

Organization: Union Carbide Corporation
Nuclear Division
P. O. Box Y, 9998, MS-2
Oak Ridge, TN 37830
(615) 574-1837

Project Goal: The FY 1980 project goal was to evaluate for LLNL specific flywheels for maximum energy storage characteristics and to improve our capabilities based upon this experience in preparation for future, more comprehensive evaluation.

Project Status: Four flywheel evaluations with FY 1980 milestones are complete. Two others are in progress.

Major Findings are as follows:

1. The Garrett AiResearch sub-circular rim flywheel with graphite spokes achieved a maximum speed of 463 rev/sec and stored a maximum energy of 1.16 kW-h at 74.4 W-h/kg.
2. The William M. Brobeck composite rim with tension-balanced spokes achieved a maximum speed of 500 rev/sec and stored a maximum energy of .295 kW-h at 25.0 W-h/kg.
3. The Hercules pre-stressed graphite disk achieved a maximum speed of 372 rev/sec and stored a maximum energy of 0.85 kW-h at 37.5 W-h/kg.
4. The Rockwell-Rocketdyne Division graphite rim with twin disk hub achieved a maximum speed of 382 rev/sec and stored a maximum energy of 1.94 kW-h at 36.1 W-h/kg.

Other data regarding radial growth, resonant frequencies, failure modes, and other test observations are reported in detail test reports.

Contract Number: W-7405-eng-26, SANL/Request 803-039

Contact Period: December 10, 1979 through December 31, 1980

Funding Level: \$385,000

Funding Source: U. S. Department of Energy through Lawrence Livermore National Laboratory.

MAGNETIC ENERGY STORAGE

PROJECT SUMMARY

Project Title: Magnetic Energy Storage Program Overview

Principal Investigator: Mitchell O. Hoenig

Organization: Francis Bitter National Magnet Laboratory
Massachusetts Institute of Technology
150 Albany Street
Cambridge, Massachusetts 02139

Due to large variations in demand, electrical utilities must produce a large fraction of their power output using premium fuels such as oil and gas. The use of diurnal energy storage would reduce power generating fuel costs, as well as reduce our reliance on imported oil, a national goal.

Superconducting Magnetic Energy Storage (SMES) does not require the conversion of electrical energy for the sake of storage. It is potentially more than 90 percent efficient. On the other hand, it represents the most advanced technology and is capital-intensive.

DOE has been supporting SMES, as well as alternate methods of energy storage for a number of years. Currently a small (8 KWH) SMES system is being built by Los Alamos Scientific Laboratory (LASL). It will be installed and operated at the Bonneville Power Administration (BPA) within a few years. Ultimately, a demonstration plant (0.5 to 50 MWH) will have to be built in order to qualify SMES for full scale (1000 to 10,000 MWH) operation. A decision to proceed with a demonstration plant will have to be made by DOE. Innovative programs, as well as technological breakthroughs, are needed in order to qualify SMES for demonstration plant funding.

Contract Number: DE-AC02-80ET26502

Contract Period: 1 September 1980 through 31 August 1981

Funding Level: \$80,000

Funding Source: U.S. Department of Energy, Division of Energy Storage

PROJECT SUMMARY

Project Title: Superconducting Magnetic Energy Storage (SMES)

Principal Investigator: John D. Rogers

Organisation: University of California
Los Alamos Scientific Laboratory
Los Alamos, New Mexico 87545
(505)-667-5427; FTS 843-5427

Project Goals: The goals of the SMES program are two-fold. These are to design, fabricate, and place into operation a 30-MJ, 10-MW SMES unit for electric utility transmission line stabilization on the Bonneville Power Administration (BPA) system by 1982-83. The second goal is to design and have constructed a SMES unit up to 10 MWh size. This unit will be for a completely detailed engineering prototype demonstration of an electric utility diurnal load-leveling system.

Project Status: The engineering design of the BPS SMES transmission line stabilization system is in an advanced state. Many large hardware items are specified and on order. The refrigerator was installed in a trailer with controls added for remote operation. Acceptance tests were performed at the factory and the unit has been delivered to the Los Alamos Scientific Laboratory (LASL). The design of the 30 MJ superconducting coil was completed by General Atomic Company (GA) with the exception of the coil top interface for dewar mounting. GA is now fabricating the coil. An engineering design of the seismic load coil support was completed. All copper and additional superconducting wire were obtained for the 5 kA cable. Development of the 5 kA cable is complete and New England Electric Wire is making the cable. The heat rejection unit has been trailer mounted and is ready for operation. Trailer installation is now contracted for the helium gas recovery system. The converter manufacture is complete and factory testing for acceptance was successfully conducted. The converter power transformers are built and undergoing factory tests. The auxiliary power transformers were obtained. The BPA site installation layout has been devised. Detailed controls design and operating logic for remote microwave link operation of the SMES unit in the BPA system are well established, and many electronic components are on order. The LASL, BPA, DOE interface working agreement was completed.

The work done on the large diurnal load leveling SMES was a preliminary 50 kA wire rope superconducting cable design and a study of SMES units on power system stability.

Contract Number: W-7405-ENG-36

Contract Period: Continuing

Funding Level: \$1,580,000 FY1980

Funding Source: Department of Energy, Division of Energy Storage Systems and Division of Electrical Energy Systems.

PROJECT SUMMARY

Project Title: A Study of the Effects of Energy Storage Inductor-Converter Units on Power System Stability

Principal Investigator: Richard T. Byerly

Organization: Westinghouse Electric Corporation
Advanced Systems Technology
East Pittsburgh, Pennsylvania 15112

Project Goals: Develop a mathematical model suitable for representing SMES units in power system stability studies. Incorporate that model into a large-scale stability program. Perform demonstration studies to illustrate the effects of SMES units on power system stability.

Project Status: The project has been completed, and the final report is in preparation.

The SMES unit model encompasses the converter and converter transformer, the converter control system, and the storage inductor. Documentation of the model is specifically intended to facilitate computer programming and includes flowcharts as well as equations and block diagrams.

The Westinghouse 2000 bus stability program has been modified to accommodate the model. Detailed instructions for data preparation for the SMES unit model have been written, including SMES unit data forms.

Demonstration studies based on two hypothetical systems have been performed, emphasizing the potential for improved damping of oscillations associated with synchronizing power flow.

The influence of an SMES unit on power system dynamic behavior depends on its storage capacity, the rating of conversion equipment, the location of the unit, its control system, and operating circumstances. These factors can be investigated in the context of large-system stability studies.

Contract Number: LASL 4-L69-6553L-1

Contract Period: September 17, 1979 through September 1, 1980

Funding Level: \$37,921

Funding Source: U.S. Department of Energy through Los Alamos Scientific Laboratory

PROJECT SUMMARY

Project Title: Superconductive Energy Storage

Principal Investigator: R.W. Boom

Organization: 531 Engineering Research Building
University of Wisconsin
Madison, Wisconsin 53706
(608) 263-5026

Project Goals: To develop hardware components, produce engineering system designs, procure manufacturing and assembly equipment designs, revise cost estimates, and assess operational efficiencies for large underground superconductive storage systems.

Project Status: Component development in three areas: cryogenics, conductor and structures is under way. Rock mechanics design and experimentation is under way. Parallel efforts supported by the Wisconsin Utilities are under way on the same schedule in five other areas: magnetica, environmental studies, system design, electrical, and safety. Two new designs have been studied: a low aspect ratio single solenoid and a 15 tunnel circular pattern of coils. These new designs may provide significant technical and economic advantages.

Contract Number: DE-AC02-76ET-26602

Contract Period: FY-80

Funding Level: \$400,000

Funding Source: U.S. Department of Energy
Division of Energy Storage

COMPRESSED AIR ENERGY STORAGE

PROJECT SUMMARY

Program Title: Compressed Air Energy Storage Technology Program

Program Manager: W. V. Loscutt

Organization: Pacific Northwest Laboratory
Richland, Washington 99352
Telephone: (509) 375-2768

Program Goals: Develop design and stability criteria for long-term operation of underground reservoirs used for CAES in order to accelerate the commercialization of the concept. Develop and assess second-generation technologies for CAES that require little or no supplementary firing by petroleum fuels in order to eliminate the dependence of CAES on these fuels.

Program Status: The reservoir stability criteria studies are progressing satisfactorily. Preliminary stability criteria for the three major types of storage reservoirs have been formulated. Generic numerical studies are complete. Most generic laboratory studies are complete. Field studies project plans have been prepared and studies are scheduled for start-up in FY-1981.

In second-generation technologies, studies have been directed at screening the major advanced technologies: thermal energy storage, fluidized bed combustion, and coal gasification. The screening is scheduled for completion in FY-1981. Decisions on more comprehensive studies and development of one or more advanced concepts are planned for FY-1981. Evaluation of equipment for advanced CAES concepts and study of new CAES concepts are continuing.

Contract Number: DE-AC06-76RLO 1830

Contract Period: FY-1980

Funding Level: \$3,160K

Funding Source: U.S. Department of Energy

PROJECT SUMMARY

Project Title: PNL Studies of Second-Generation CAES Concepts

Principal Investigator: M. K. Drost, R. W. Reilly, F. R. Zaloudek

Organization: Battelle
Pacific Northwest Laboratory
Richland, Washington 99352

Project Goals: These tasks have the general objective of providing the technical and economic information to support recommendations to DOE/STOR on the development of advanced CAES plants.

Project Status: This summary covers the three major tasks performed at PNL.

Feasibility of CAES/CG - An assessment was made of the technical and economic viability of a CAES plant based on a cycling gasifier in an utility peaking application. The results indicated that this CAES concept may not be as technically and economically viable as other concepts under consideration in this program.

Advanced Concepts Technical Analysis and Support - Preliminary technical and economic assessments were completed for several candidate CAES concepts including 1) a combined CAES and steam plant, 2) ACAES using an aquifer for the combined storage of heat and compressed air and 3) an integrated CAES/solar plant.

Comparative Economics of Advanced Concepts - A methodology was developed to place the various CAES and advanced concepts CAES studies on the same economic bases to allow direct comparisons of capital and power costs. This methodology was applied to data from engineering and economic studies already completed and preliminary comparisons made. The study will be completed in FY-1981.

Contract Number: DE-AC06-76RLO 1830

Contract Period: October 1979 through September 1980

Funding Level: \$83K

Funding Source: U.S. Department of Energy

PROJECT SUMMARY

Project Title: Technical and Economic Assessment of Fluidized Bed Augmented Compressed Air Energy Storage System

Principal Investigator: Robert D. Lessard

Organization: United Technologies Research Center
Silver Lane
East Hartford, Connecticut 06108

Project Goals: (1) Assess fluid bed combustor (FBC) and turbomachinery technology relative to their integration potential in compressed air energy storage (CAES) applications; (2) Identify a preferred CAES/FBC power plant system configuration; (3) Transform the selected CAES/FBC system configuration into a preconceptual power plant design; and (4) Evaluate the part-load and load-following capabilities of the selected CAES/FBC power plant.

Project Status: The efforts related to achieving the first three of the four goals mentioned above have been completed and documented in United Technologies Report No. R80-954490-20. The analysis and initial documentation for the fourth goal, evaluation of part-load capability, have been completed.

The major conclusions of the study are as follows:
(1) coal-fired CAES/FBC systems should be technically feasible in the near future, (2) a CAES/open-bed PFBC configuration would provide the best candidate for early commercialization; (3) a CAES/PFBC power plant could be designed and built by utilizing many standard equipment items and modifying existing equipment designs; (4) the economic competitiveness of the CAES/PFBC is attractive for peak- to mid-load power generation; and (5) preliminary indications are that a CAES open-bed PFBC should have good part-load and load following capabilities.

Contract Number: EY-76-C-06-1830, Subcontract B-51299-A-L

Contract Period: 1 November 1978 through 31 December 1980

Funding Level: \$355,994 (through 30 September 1980)

Funding Source: U. S. Department of Energy through Pacific Northwest Laboratory operated by Battelle Memorial Institute

PROJECT SUMMARY

Project Title: Conceptual Design of Adiabatic CAES in Hard Rock

Principal Investigator: M.J. Hobson

Organization: Acres American Incorporated
Columbia, Maryland 21044

Project Goals: Determine near-term technical and economic feasibility of adiabatic CAES with hard rock cavern storage.

Project Status: Technical activities completed, reports being finalized covering the five project tasks.

Task I involved technology review, storage material cost/performance assessment and analysis of the Thermal Energy Storage (TES) system. A sensible heat pebble bed approach was selected and several candidate storage materials were identified.

Task II involved technology review, development of a turbomachinery configuration, identification of performance, cost and future potential for development of more efficient plant equipment.

Task III involved cycle optimization based upon real machinery limitations and estimation of performance over the operating range.

Task IV involved development of a 4-unit conceptual plant design based upon the site used for the recent PEPCO CAES/UPH study.

Task V involved estimation of plant construction and operating costs and development of comparative energy production costs.

Contract Number: EY-76-C-06-1830, Subcontract B-82284-A-E

Contract Period: December 1979 - December 1980

Funding Level: \$249,353

Funding Source: U.S. Department of Energy through Battelle-Pacific Northwest Laboratory

BEST DOCUMENT AVAILABLE

PROJECT SUMMARY

Project Title: Fluid/Thermal Analysis of Porous Media Reservoirs for CAES

Project Investigators: R. A. McCann, L. E. Wiles

Organization: Pacific Northwest Laboratory
Richland, Washington 99352

Project Goals: Perform a parametric analysis to evaluate the potential for water coning to occur. Demonstrate the capability to perform bubble development calculations.

Project Status: The above goals were accomplished in FY-1980 through the development of a computer model to describe multi-dimensional, multi-phase flow in porous media. Finite difference methods were used.

Water coning may occur when a CAES reservoir is being discharged if the air storage zone is bounded from below by a water bearing region. During the discharge, the pressure drop around the wellbore provides a gradient whereby a cone of water may rise towards the wellbore with adverse effects on the performance of the well. The parameters studied included the wellbore producing length, reservoir thickness, flow rates, permeability, and the saturation functions. The primary conclusion of the study was that water coning should not be a problem for CAES.

Full scale air storage bubble development in an aquifer may require significant time periods. The multiphase flow model has the capability to optimize the procedure by evaluating injection strategies and well locations. Generic bubble development analysis capability has been demonstrated with adapted versions of the code, and confirmatory calculations have been performed. Simplified analytic solutions were matched. The model has multiple source and sink capability and a variety of geometries.

Contract Number: DE-AC06-76RLO 1830

Contract Period: Oct. 1, 1979 - September 30, 1980

Funding Level: \$135K

Funding Source: U.S. Department of Energy

BEST DOCUMENT AVAILABLE

PROJECT SUMMARY

Project Title: Evaluation of Thermomechanical Properties of Galesville Sandstone under CAES Conditions

Principal Investigator: James D. Blacic

Organization: Los Alamos National Laboratory
Geophysics Group
Los Alamos, NM 87545

Project Goals: Experimentally determine the elastic and strength properties of a typical CAES sandstone as a function of temperature, effective pressure, and cyclic stress application.

Project Status: The project has been completed. It consisted of two tasks.

In Task I, Young's modulus, Poisson's ratio, ultimate strength, and coefficients of internal and sliding friction were determined at 37 to 204°C and 0-31 MPa effective pressure.

In Task II, elastic and strength properties were determined after repeatedly applying stresses of 10-30% of failure stress for 100, 1000, and 10,000 cycles. The same values of temperature and effective pressure were used as those in Task I.

Major conclusions are: (1) Young's modulus increases and Poisson's ratio decreases with increasing effective pressure and temperature. Both effects appear to be due to densification of the sandstone, (2) Mohr failure envelopes are nonlinear due to plastic flow of the dolomite cement, but strengths are well above stresses induced by probable CAES operating conditions, (3) Coefficient of sliding friction decreases with increasing temperature and effective pressure. Frictional sliding along preexisting discontinuities in a CAES reservoir are possible at probable CAES operating conditions. (4) Low stress cyclic loading affects elastic constants in the same way as in (1), and is also probably due to pore volume reduction. No change in strength due to cyclic loading was detected.

It is recommended that (1) Trends in elastic constant changes be incorporated into thermomechanical models of a CAES reservoir, (2) Possible displacement along preexisting joint, fracture, bedding, etc. planes in a CAES reservoir be evaluated, (3) Possible reduction of reservoir permeability due to densification be evaluated.

Contract Number: Subcontract B63737-A-H with Pacific Northwest Laboratory, Prime Contract DE-AC06-76RLO 1830

Contract Period: March 1979 - September 1980

Funding Level: \$133K

Funding Source: U.S. Department of Energy through Pacific Northwest Laboratory

PROJECT SUMMARY

Project Title: Physicochemical Properties Analysis of Massillon Sandstone in Support of the Compressed Air Energy Storage (CAES) Program

Principal Investigator: Craig H. Cooley

Organization: Terra Tek Inc.
420 Wakara Way
Salt Lake City, Utah 84108

Project Goals: Identify the physicochemical phenomena that would likely reduce the permeability of reservoir rocks subjected to CAES operating conditions. Conduct laboratory tests subjecting Massillon sandstone samples to simulated CAES conditions to quantify the permeability reductions due to the above identified phenomena.

Project Status: The project is complete. It consisted of three phases.

Phase I: A seminar was held at Terra Tek with leading researchers in the field of porous media physics and chemistry. The important phenomena likely to occur in reservoir rocks subjected to CAES conditions were prioritized by their impact on permeability.

Phase II: Existing flow equipment at Terra Tek was modified to provide the temperature and pore fluid flow typical of CAES.

Phase III: Massillon sandstone samples were permeability tested under simulated CAES conditions.

Major Conclusions: The phenomena discussed during Phase I that were felt may drastically alter permeability were found not to cause large permeability reductions (i.e. greater than ~50% of the original permeability values) in Massillon sandstone at 150°C temperatures with deionized water and 2% KCl brine pore fluids.

Further site specific testing is recommended since Massillon sandstone which is largely clay free and relatively strong approaches an ideal reservoir material. Significant permeability degradation may occur in less ideal reservoir rocks subjected to CAES conditions.

Contract Number: Subcontract B82282-A-H with Pacific Northwest Laboratory, Prime Contract DE-AC06-76RL0 1830

Contract Period: December 1, 1979 - October 31, 1980

Funding Level: \$74,936

Funding Source: U.S. Department of Energy through Pacific Northwest Laboratory

BEST DOCUMENT AVAILABLE

PROJECT SUMMARY

Project Title: Underground Compressed Air Energy Storage - Rock Mechanics and Geology Components

Principal Investigator: Howard J. Pincus

Organization: University of Wisconsin-Milwaukee
PO Box 413
Milwaukee, WI 53201

Project Goals: Evaluate the effects of pressure-temperature cycling with compressed air on underground reservoir rocks and their associated caprocks.

Project Status: The project, begun in January 1977 and renewed annually each fiscal year, has been completed. In FY-1980, primary emphasis was placed on studying the effects of cyclic ventilation on core samples of one candidate reservoir-rock, the Mt. Simon Sandstone. Independent variables were air-temperature, amplitude of the air-pressure cycle, and the number of cycles. Dependent variables were permeability, porosity, Young's modulus, compressive strength, weight, thermal conductivity, heat capacity, linear thermal expansion, and the optical correlation coefficient (measure of fabric change).

Major conclusions are as follows: the critical variables of air movement affecting properties of susceptible reservoir rocks are air-temperature and amplitude of the air-pressure cycle. The most sensitive dependent variable is permeability, which may increase or decrease with ventilation; observed decreases have been small.

Based on all of the work conducted since this project was initiated, the most important factor studied is the makeup of the rock itself. The best candidate for reservoir rock appears to be clean quartz-sandstone, medium-to coarse-grained, well-sorted, and moderately cemented with silica. The best example of such a rock from among those studied is St. Peter Sandstone. Promising sandstone reservoir rocks in the upper midwest are Mt. Simon, Eau Claire (greensand), Galesville, and St. Peter. Favorable structures may be concentrated along the Kankakee Arch and the Midcontinent Gravity High. Structures that have already been used successfully for gas storage are technically attractive.

Contract Number: Subcontract B-82289-A-K with Pacific Northwest Laboratory, Prime Contract DE-AC06-76RLO 1830, UWM account number 144-P005

Contract Period: October 1, 1979 - November 30, 1980

Funding Level: \$56,177

Funding Source: U.S. Department of Energy through Pacific Northwest Laboratory

PROJECT SUMMARY

Project Title: Analytical Modeling of Champagne Effect Hydraulically Compensated CAES Reservoir

Principal Investigator: D.S. Rowe, C.A. McMonagle

Organization: Rowe & Associates
14400 Bellevue-Redmond Road, Suite 208
Bellevue, WA 98007

Project Goals: Develop an analytical model to determine if blowout is a problem in Compressed Air Energy Storage (CAES) systems and to determine which parameters are most sensitive to that assessment.

Project Status: An analytical model has been developed and a variety of conservatively oriented calculations have been performed which indicate that the Champagne Effect is unlikely to cause blowout for a properly designed CAES system.

A one-dimensional analytical model is used to represent the entire system consisting of the air-pipe, storage cavern, compensation pipe, and surface reservoir. Thermo-hydraulic aspects of air, water, and dissolved air are modeled using the two-fluid approach and conservative constitutive relationships are utilized in system calculations. Variations in design and constitutive relationships have been studied to show that a reduction of dissolved air, an increase of friction, and a deep compensation reservoir would mitigate the Champagne Effect. Most conservative results are obtained for homogeneous flow and for equilibrium deaeration of the water. Best estimate calculations of CAES operation could be done through a refinement of constitutive relations and validation with experimental data.

Contract Number: DE-AC06-76RLO 1830; Subcontract B-43388-A-L

Contract Period: Fiscal Year 1980

Funding Level: \$37,000

Funding Source: U.S. Department of Energy through Pacific Northwest Laboratories

PROJECT SUMMARY

Project Title: CAES Reservoir Stability Criteria

Principal Investigator: L.D. Kannberg

Organization: Battelle
Pacific Northwest Laboratory
Richland, Washington 99352

Project Goals: Develop design and stability criteria for CAES underground reservoirs.

Project Status: Preliminary stability criteria have been completed for candidate rock types (salt, porous rock, hard rock). Research needs were identified and were pursued by numerical modeling and laboratory studies. A site has been identified and confirmed for testing of CAES in porous rock.

Numerical modeling of porous rock reservoirs concentrated on well coning and on air bubble development. Laboratory work addressed porous rock structural and hydraulic response to cyclic flow of various fluids at elevated pressures and temperatures. A site was identified in west-central Illinois for small-scale field testing.

Numerical modeling of salt proceeded with analysis of cavern response to thermal and cyclic thermal and mechanical loads. Laboratory and in-mine work concentrated on determining basic strength characteristics of salt from various sites, permeability of salt in mines, and strain and acoustic emission from cyclically loaded salt specimens. A field site was selected for testing. However, activity has been postponed indefinitely.

Numerical modeling of hard rock caverns continued to develop basic design nomograms and address CAES specific cavern stability concerns (cyclic thermal and mechanical loading). Laboratory efforts concentrated on response of typical hard rocks to cyclic loads at elevated temperatures and strength reduction due to enhanced weathering. No field studies are planned in hard rock.

Contract Number: DE-AC06-76RLO 1830

Contract Period: October 1979 to September 1980

Funding Level: \$2,070,000

Funding Source: U.S. Department of Energy

PROJECT SUMMARY

Project Title: Numerical Modeling of Behavior of Caverns in Salt for CAES with Elevated Temperatures

Principal Investigator: Dr. Shosei Serata

Organization: Serata Geomechanics, Inc.
1229 Eighth Street
Berkeley, CA 94710

Project Goals: Establish critical design parameters affecting the long term stability of CAES caverns and investigate the sensitivity of cavern behavior to variations in these parameters using finite element analysis.

Project Status: The project is 90% complete. It has consisted of four phases:

In Phase I, REM, a finite element code specifically suited for underground cavities structural analysis in salt, was interfaced with *HEAT*, a general heat transfer finite element code. The REM code was modified to incorporate temperature and air penetration effects.

In Phase II a specific structural analysis problem given by PNL to illuminate the capabilities of REM and *HEAT*, primarily with respect to cyclic analysis, was completed.

Phase III, a single cavern parametric analysis of a prospective CAES site, was completed. It consisted of two parts. First, a preliminary pie-slice analysis, to determine the ranges of the critical parameters, was made. Second, a full cavern axisymmetric analysis, to focus on specific ranges shown to be of importance, was made.

In Phase IV an analysis of a particular test borehole in the Jefferson Island mine being monitored by LSU was undertaken. It is 75% complete.

Major conclusions are as follows: 1) In situ lateral stress is the most dominant parameter governing long term cavern behavior. Stability is greatly reduced as the in situ lateral stress approaches the theoretical limit. 2) Given that other critical parameters maintain moderate values, CAES caverns are structurally very stable in the long term for temperatures to 200°F. 3) Air penetration and boundary deterioration primarily affect the local stability of CAES caverns and have relatively minor significance in determining the global stability. 4) At cavern length to width ratios of less than 8, the supporting effect of the roof and floor greatly reduces radial strain. 5) Cycling of pressure and temperature has only a minor effect on long term cavern behavior.

The results of this study indicate that the most important aspect of further work will be determining the quantitative aspects of material deterioration by brittle creep due to air penetration into granular salt interstitial space under CAES operating conditions.

Contract Number: DE-AC06-76RLO 1830, Subcontract B-82290-A-P

Contract Period: January 22, 1980 through September 30, 1980

Funding Level: \$70,792

Funding Source: Department of Energy through Pacific Northwest Laboratory

PROJECT SUMMARY

Project Title: Laboratory Tests of Salt Specimens Subjected to Loadings and Environmental Conditions Appropriate to a Compressed Air Energy Storage Reservoir.

Principal Investigator: Robert L. Thoms

Organization: Institute for Environmental Studies
Louisiana State University
Baton Rouge, LA 70803

Project Goals: To test rock salt under conditions simulating effects of compressed air energy storage (CAES) in salt, and to formulate long-term stability criteria for CAES salt caverns.

Project Status: Salt has been obtained from 7 U.S. Gulf Coast domes and one West German dome (Huntorf), and from a salt deposit in northwest Arizona. Jefferson Island dome salt from south Louisiana has been tested under cyclic triaxial extension for over 2000 hours and approximately 84,000 loading cycles. Salt specimens from six sources (3 each) have been tested in a Brazilian "index" testing series.

In-situ bench-scale experiemnts are underway in two south Louisiana salt mines, i.e., Cote Blanche and Jefferson Island. Qualitative gas permeability tests have been performed by injecting Freon 12 into one hole and checking nearby holes for cross-borehole flow. Further, preliminary cyclic pressurization borehole tests have been performed.

Major conclusions to date are: (a) permeability of rock salt depends on confining pressure and loading history, (b) results from Brazilian tests indicate salt behaves similarly from U.S. Gulf Coast domes, (c) acoustic emissions permit monitoring of cyclic load effects on salt.

Recommendations include: (a) perform in-situ permeability tests at several locations in a salt mine to check effects of varying salt character, (b) continue long-term tests on salt in laboratory so as to build a data base to formulate quantitative criteria for CAES salt reservoirs.

Contract Number: B-67966-A-H

Contract Period: 1 October 1978 through 30 September 1980

Funding Level: \$324,166

Funding Source: U.S. Department of Energy through Battelle-Pacific Northwest Laboratory

PROJECT SUMMARY

Project Title: Numerical Modeling to Predict Behavior of Underground Hard Rock Caverns Used for Compressed Air Energy Storage

Principal Investigator: Arlo F. Fossum

Organization: RE/SPEC Inc.
P.O. Box 725
Rapid City, SD 57709
(605)-343-7868

Project Goals: Develop and use numerical models to evaluate the behavior of compensated CAES caverns in hard rock and establish a methodology for the development of stability criteria.

Project Status: The generic portion of the project is nearing completion. It consists of two major phases. The first phase has been completed. The second phase will be completed in September, 1980.

In Phase 1 the major generic rock property characteristics were established, a conceptual numerical CAES simulation model was formulated, and modeling procedures were established for the construction and operational stages of a CAES cavern.

In Phase 2 parametric analyses were made of the excavation and operation of a CAES cavern, precedent information was gathered for underground storage caverns in Scandinavia, and studies were made of the influence of joints on the potential for rock failure around a cavern. Numerical modeling of remedial action is in progress.

Upon completion of the generic phase of the project, a site specific analysis will be performed on the PEPCO CAES site. The CAES analysis methodology developed in the generic phase will be used to design stable caverns for the PEPCO operating cycle and to evaluate the Acres American design of the PEPCO caverns.

Contract Number: Special Agreement No. B-49407-A-H/Prime Contract EY-76-C-06-1830

Contract Period: August 31, 1978 through September 30, 1980

Funding Level: \$276,431

Funding Source: U.S. Department of Energy through Pacific Northwest Laboratories, Battelle Memorial Institute

PROJECT SUMMARY

Project Title: Establishment of Design and Stability Criteria Through Laboratory Testing of Hard Rock Specimens Subjected to Loadings and Environmental Conditions Appropriate to a Compressed Air Energy Storage Cavern

Principal Investigator: Arlo F. Fossum

Organization: RE/SPEC Inc.
P.O. Box 725
Rapid City, SD 57709
(605)-343-7868

Project Goals: Investigate the properties of hard rock specimens, from formations suitable for CAES under the cyclic conditions imposed by a CAES installation, by means of laboratory scale testing; and to formulate preliminary design and stability criteria for CAES caverns.

Project Status: The generic portion of the project has been completed. It consisted of five main tasks.

In Task 1 the rock properties important to CAES were determined. A literature survey was completed to assess areas where data were lacking. Representations were established between a rock's thermal properties and its petrography.

In Task 2 hard rock specimens were procured and prepared for testing.

In Task 3 the mineralogical composition of all selected rock types was determined for the purpose of rock characterization.

In Task 4 the rock specimens were tested under conditions appropriate to a CAES storage cavern.

In Task 5 the results of this program and other previously PNL sponsored programs were scrutinized to arrive at a set of guidelines to be used by designers of CAES caverns.

Contract Number: Special Agreement No. B-512958-A-E/Prime Contract
EY-76-C-06-1830.

Contract Period: March 2, 1979, through August 5, 1980

Funding Level: \$205,925

Funding Source: U.S. Department of Energy through Pacific Northwest Laboratories, Battelle Memorial Institute

PROJECT SUMMARY

Program Title: CAES Air/Water/Rock Interactions

Principal Investigator: James A. Stottlemire

Organization: Battelle
Pacific Northwest Laboratory
Richland, Washington 99352

Project Goals: Conduct laboratory-scale experiments in support of the development of elevated temperature CAES reservoir design and operating criteria.

Project Status: Results from PNL autoclave investigations of Galesville sandstone indicate good porosity and permeability stability at temperatures of up to 300°C for a dry air environment. However, in a humid air or liquid water environment, some sandstone disaggregation was observed at temperatures greater than 150°C.

Results from PNL corrosion tests of three carbon steel well casing materials indicate an acceptably low corrosion rate even in humid air environments at 300°C. Some concern remains regarding the physical stability of the corrosion product (hematite) and the possibility of particulate entrainment in the air stream.

Experiments at Terra Tek Inc. indicate that flooding of silica-cemented sandstones with hot water may result in permeability reductions without sample compaction. Particulate plugging appears to be the cause and the magnitude may be rock-type dependent. Tests at the University of Wisconsin-Milwaukee reveal that cyclic ventilation of sandstones with warm dry air does not significantly degrade rock properties. Future work will focus on the effects of hot humid air to span the gap between dry air and liquid water results.

Results from experiments at Los Alamos Scientific Laboratory reveal that for carbonate cemented sandstone the elastic "constants" are temperature and stress dependent apparently caused by densification. Low stress cyclic loading has little effect on elastic "constants" until 10^3 cycles at 50 and 120°C and 10^4 cycles at 200°C.

Contract Number: DE-AC06-76RLO 1830

Contract Period: October 1979 to September 1980

Funding Level: \$299K

Funding Source: U.S. Department of Energy

PROJECT SUMMARY

Project Title: Field Studies of Porous Rock Reservoirs

Principal Investigators: N. Rudd, Robert D. Allen

Organization: Battelle
Pacific Northwest Laboratory
Richland, Washington 99352

Project Goals: Demonstrate the feasibility of storage and cycling of warm compressed air in an aquifer.

Investigate physical, chemical, mineralogical, and biological effects of CAES on reservoir rock and caprock and compare with laboratory results.

Verify and evaluate numerical modeling of dehydration and water displacement, thermal growth, and cyclic thermal performance.

Evaluate system performance with respect to bubble growth rate, mass transfer rates, thermal recovery, water production, and entrainment of mineral particles.

Project Status: The aquifer field plan is complete. It includes program management, site-selection procedures, test plan development, field setup and operation, activity schedule for FY-1980 through 1982, and projected expenditures.

A doubly plunging anticline situated in Pike County west of Pittsfield, Illinois, has been identified. It is characterized by substructural domes, some of which are believed suitable for small scale CAES and testing. The detailed structure and lithology, based upon high resolution shallow seismic surveying, borehole drilling, geophysical logging, and core examination and physical analysis show at least one promising dome. An RFP has been issued to solicit proposals for air injection/withdrawal tests at the site.

Contract Number: DE-AC06-76RLO 1830

Contract Period: October 1979 to September 1980

Funding Level: \$548,000

Funding Source: U.S. Department of Energy

SEASONAL THERMAL ENERGY STORAGE

PROJECT SUMMARY

Project Title: Seasonal Thermal Energy Storage Program

Principal Investigator: James E. Minor

Organization: Pacific Northwest Laboratory
P.O. Box 999
Richland, Washington 99352
(509) 376-0694 (FTS: 444-0694)

Project Goals: Demonstrate the economic storage and retrieval of energy on a seasonal basis, using heat or cold available during a surplus period to reduce peak period demand; reduce electric utilities peaking problems; and contribute to the establishment of favorable economics for solar heating and cooling systems.

Seasonal storage in aquifers will be evaluated in the Aquifer Thermal Energy Storage (ATES) Demonstration Program. A parallel Technical Support Program will provide data on aquifer behavior, data from field tests and economic and mathematic modeling data. Previous work on earth storage, and work under the International Energy Agency on pond, lakes, tanks, and constructed caverns will be evaluated and additional field tests or demonstrations recommended, if appropriate.

Project Status: Conceptual design studies, including aquifer characterization, have been initiated at three sites. This Phase I work will be completed in FY-1982.

Eight technical support tasks have been initiated. Contracted work under these tasks is discussed individually. The field test site for lower temperature tests (55-125°C) has been redesigned and completion of the modified well field is in progress.

Evaluation of existing data for other methods of seasonal storage is proceeding, and IEA work on seasonal storage methods is being monitored.

Contract Number: DE-AC06-76RLO 1830

Contract Period: Continuing

Funding Level: FY-1980 \$5,190K BO/\$5,729K BA

Funding Source: U.S. Department of Energy, Office of Advanced Conservation Technologies

PROJECT SUMMARY

Project Title: Aquifer Thermal Energy Storage Program Management

Principal Investigator: Kenneth Fox

Organization: Pacific Northwest Laboratory
P.O. Box 999
Richland, Washington 99352
(509) 376-0891 (FTS: 444-0891)

Project Goals: The initial goal of this program is to establish conceptual design contracts with the maximum number of potential demonstration contractors. After these contracts are in place the principal task in Phase I is the characterization of the aquifers for conceptual designs. The functional design criteria for the above ground portions will then be added to complete the conceptual designs.

From the Phase II proposals submitted at the end of Phase I we will establish the maximum number of Phase II contracts allowed by funding and technical considerations. During Phase II we will design, construct, startup, and operate the aquifer demonstrations to demonstrate aquifer storage feasibility (economic, technical, environmental and institutional) in operating demonstrations.

Project Status: Three conceptual designs are in place. The initial plans for management, aquifer characterization, environmental and institutional work are complete.

Aquifer characterization is in progress at all three sites.

Functional design criteria are being prepared.

Contract Number: DE-AC06-76RLO 1830

Contract Period: Continuing

Funding Level: \$371,000, FY-1980, B/O

Funding Source: U.S. Department of Energy, Office of Advanced Conservation Technologies

PROJECT SUMMARY

Project Title: Bethel, Alaska, Aquifer Thermal Energy Storage Project

Principal Investigator: Jack M. Cherne

Organization: TRW
One Space Park
Redondo Beach, California 90278
(213) 535-4321

Project Goals: The first goal is to identify and characterize a viable aquifer. Concurrently, a conceptual design for an ATES system will be developed, including an energy source, thermal transport, storage aquifer and users. During the study, the economic viability of the conceptual system will be established, and the institutional and environmental concerns for future development will be identified. The products of Phase I will be a complete conceptual design for Phase II and a plan for a Phase II program.

Project Status: All plans, management, environmental, institutional, and aquifer characterization have been written and approved by PNL. All environmental and institutional requirements for obtaining permits for drilling and testing the wells for aquifer characterization have been accomplished. Roads and pads for all drilling have been designed and construction started.

A well driller has been selected and the drilling has started. Drilling is expected to be complete by mid-November 1980.

A test transfer loop using the Bethel Utility Corporation diesel cooling water has been designed for use in the injection tests. A contractor to build this system has been selected. All instrumentation for the test wells has been procured. Testing the wells (production, injection and measurement of temperatures, pressures and flows) will be started in November and completed in December.

Contract Number: DE-AC06-76RLO 1830, Subcontract B-68264-A-G

Contract Period: 1 May 1980 through 31 January 1982

Funding Level: \$1,888,126

Funding Source: U.S. Department of Energy through Pacific Northwest Laboratory

BEST DOCUMENT AVAILABLE

PROJECT SUMMARY

Project Title: Stony Brook, New York, Aquifer Thermal Energy Storage Demonstration Project

Principal Investigator: William V. Skinner

Organization: Dames & Moore
6 Commerce Drive
Cranford, New Jersey 07016
(201) 272-8300

Project Goals: The first goal is to identify and characterize a viable aquifer. Concurrently, a conceptual design for an ATES system will be developed, including an energy source, thermal transport, storage aquifer and users. During the study, the economic viability of the conceptual system will be established, and the institutional and environmental concerns for future development will be identified. The products of Phase I will be a complete conceptual design for Phase II and a plan for a Phase II program.

Project Status: The Management Plan, Aquifer Characterization Plan, and Environmental Plans have been submitted to PNL and approved with some modifications pending.

The preliminary assessment of available pumps and wells is complete and it appears that the existing equipment is usable.

Drilling is in progress at the doublet test site and is progressing satisfactorily.

Preparations are being made to provide chilled water for the chill injection tests.

Facilities assessment and evaluation are in progress. The survey of the existing systems is about two (2) weeks behind schedule.

Doublet tests are scheduled to start in mid-October.

Contract Number: DE-AC06-76RLO 1830, Subcontract B-67775-A-G

Contract Period: 16 May 1980 through 31 May 1982

Funding Level: \$797,594

Funding Source: U.S. Department of Energy through Pacific Northwest Laboratory and New York Energy Research Development Agency

PROJECT SUMMARY

Project Title: Aquifer Thermal Energy Storage System at the University of Minnesota

Principal Investigator: Warren E. Soderberg

Organization: University of Minnesota
319 15th Avenue S.E.
Minneapolis, Minnesota 55455
(612) 373-2001

Project Goals: The first goal is to identify and characterize a viable aquifer. Currently, a conceptual design for an ATES system will be developed, including an energy source, thermal transport, storage aquifer and users. During the study, the economic viability of the conceptual system will be established, and the institutional and environmental concerns for future development will be identified. The products of Phase I will be a complete conceptual design for Phase II and a plan for a Phase II program.

Project Status: The project is in its initial stages of construction and design. A contract to core three (3) holes was awarded in August 1980 to provide a complete core sample for laboratory testing and analysis, and to log the entire stratigraphic sections.

Plans and specifications for six (6) monitoring wells and the two (2) pumping wells (300 gpm) as well as above ground mechanical and electrical equipment necessary to perform the testing of the aquifer storage theory will be issued in September for bidding. Construction is planned for completion by March 31, 1981. Heat injection testing is planned to start April 15, 1981.

The testing will involve heating the aquifer water from supply well at an ambient temperature of (12°C) to 100°C and injection into the aquifer at a distance of 240 meters for a period of eight (8) days, rest eight (8) days, and then the flow reversed for eight (8) days. Upon removal, the injected water will be passed through heat exchangers lowering the temperature to 80°C prior to reinjecting into the supply well. This procedure is repeated using the supply well water temperature of 80°C to 125°C through a heat exchanger prior to injection into the injection well and the cycle repeated as above.

The next cycle will take the supply water at 80°C and raise it to 150°C. At least two additional cycles will be run at this design condition and all taken, recorded and analyzed, thus completing the test phase from which an aquifer characterization plan will be made. From this a Phase II design concept will be developed.

Contract Number: DE-AC06-76RLO 1830, Subcontract B-97601-A-G

Contract Period: 21 May 1980 through 1 July 1982

Funding Level: \$1,936,431

Funding Source: U.S. Department of Energy through Pacific Northwest Laboratory

PROJECT SUMMARY

Project Title: Technical Support Program Management

Principal Investigator: Jay R. Eliason

Organization: Pacific Northwest Laboratory
P.O. Box 999
Richland, Washington 99352
(509) 376-0115 (FTS: 444-0115)

Project Goals: The Technical Support Program is designed to conduct research and development studies required to provide a sound technical base for the demonstration and commercialization of seasonal thermal energy storage concepts.

Project Status: The Technical Support Program has been organized into the following tasks: Legal/Institutional Assessment; Economic Assessment; Environmental Assessment; Field Test Facilities; Compendia; Laboratory Analysis; Numerical Simulation; and Non-Aquifer STES Concepts. The first seven tasks are initially emphasizing development of technical support for the ATEs Demonstration Program. Progress for individual tasks is identified in separate project summaries.

A Consultant Review Team which provides a technical review of the program has been established to provide an independent overview of program activities on a continuing basis. Recommendations made by the Consultant Review Team provide guidance for planning and conducting the program. The Consultant Review Team at this time is composed of the following individuals: Stanley N. Davis, Professor, Department of Hydrology and Water Research, University of Arizona; Robert D. MacNish, Chief, Arizona District, U.S. Geological Survey; Donald Langmuir, Professor, Department of Chemistry and Geochemistry, Colorado School of Mines; Arthur C. Riese, Senior Geochemist, Gulf Research and Development Company; David L. Schreiber, CRT Coordinator, Consulting Hydraulic Engineer; and John F. Spencer, Assistant Director, Washington State Department of Ecology.

Contract Number: DE-AC06-76RLO 1830

Contract Period: Continuing

Funding Level: \$265,000, FY-1980, B/O

Funding Source: U.S. Department of Energy, Office of Advanced Conservation Technologies

PROJECT SUMMARY

Project Title: Legal/Institutional Assessment

Principal Investigator: Paul L. Hendrickson

Organization: Pacific Northwest Laboratory
P.O. Box 999
Richland, Washington 99352
(509) 376-4253 (FTS: 444-4253)

Project Goals: Investigate the legal and regulatory issues that will affect implementation of STES concepts.

Project Status: The initial review of ATES related issues has been completed and the report has been published, "Legal and Regulatory Issues Affecting the Aquifer Thermal Energy Storage Concept" as PNL 3437. Additional work in this general subject area will be conducted in FY-1981-82 by the author.

The investigation focused on the following categories of issues: regulatory requirements prior to ATES operation, the types of property rights needed to store and recover the energy resource and the alternative means to acquire the needed rights, potential areas of liability, and institutional and financial issues applicable to delivery of the stored energy.

The principal regulatory considerations prior to operation are acquisition of needed ground-water withdrawal and reinjection permits. Requirements will be mainly at the state level, but could occur at the Federal level under the authority of the Safe Drinking Water Act.

Surface and subsurface activities that could potentially lead to liability and approaches to mitigating possible liability were considered. The investigation of legal and regulatory issues affecting end use of the stored energy resource will be expanded in 1981.

Contract Number: DE-AC06-76RLO 1830

Contract Period: Continuing

Funding Level: \$46,000, FY-1980, B/O

Funding Source: U.S. Department of Energy, Office of Advanced Conservation Technologies

PROJECT SUMMARY

Project Title: Economic Assessment

Principal Investigator: Raymond Wm. Reilly

Organization: Pacific Northwest Laboratory
P.O. Box 999
Richland, Washington 99352
(509) 376-4359 (FTS: 444-4359)

Project Goals: Conduct economic analyses and related investigations for all phases of the Seasonal Thermal Energy Storage (STES) Program.

Project Status: The project consisted of four major activities. The first two are complete, and the second two will be completed during FY-1981.

A literature search was made to document the technical, environmental, economic, and institutional aspects of the Aquifer Thermal Energy Storage (ATES) technology. The results were published in A Descriptive Analysis of Aquifer Thermal Energy Storage Systems, June 1980.

A work statement was designed and an external contract was let to develop Guidelines for Conceptual Design and Evaluation of Aquifer Thermal Energy Storage Systems. The document was published in October 1980.

A computer code has been developed and is operational for analysis of the economics of ATES systems. The code: AQUASTOR, simulates the development and operation of an aquifer storage system (including transmission and distribution systems) to develop a life-cycle cost for delivered thermal energy (heat or chill). AQUASTOR will undergo refinement, through checkout, and documentation during FY-1981, and will then be made available for public use.

Preliminary investigations were made into the economics of chill storage in aquifers (in conjunction with development of AQUASTOR). In-depth, site-specific analyses of chill storage will be conducted during FY-1981.

Contract Number: DE-AC06-76RLO 1830

Contract Period: Continuing

Funding Level: \$99,000, FY-1980, B/O

Funding Source: U.S. Department of Energy, Office of Advanced Conservation Technologies

PROJECT SUMMARY

Project Title: Development of a Methodology for Conceptual Design and Evaluation of Aquifer Thermal Energy Storage (ATES) Systems. (Short Title: ATES Guidelines.)

Principal Investigator: Charles F. Meyer, Walter Hausz

Organization: General Electric Company
GE-TEMPO
Santa Barbara, California 93102
(805) 965-0551

Project Goals: To develop and present guidelines as a tool for those considering use of a new technology, ATES. The guidelines will assist in the conceptual design and the evaluation of technical and economic feasibility of systems employing ATES.

Project Status: The project has been completed.

Chapters 1 and 2 of the Guidelines, totaling seven pages, describe the potential benefits of ATES, give an overview of the technology and its application, and provide rules of thumb for quickly judging whether a proposed project has sufficient promise to warrant detailed conceptual design and evaluation.

The balance of the document discusses the characteristics of sources and end uses for heat and chill which are seasonally mismatched and may benefit from ATES (industrial waste heat, solar heat, winter chill, and cogeneration, for space heating and air conditioning); describes storage and transport subsystems and their expected performance and cost, as best these parameters are now known; presents a 10-step methodology for conceptual design of an ATES system and evaluation of its technical and economic feasibility, with examples; and applies the methodology to a hypothetical proposed ATES system, to illustrate its use.

Contract Number: DE-AC06-76RLO 1830, Subcontract B-67764-A-0

Contract Period: 12 February 1980 through 30 September 1980

Funding Level: \$95,357

Funding Source: U.S. Department of Energy through Pacific Northwest Laboratory

PROJECT SUMMARY

Project Title: Environmental Assessment

Principal Investigator: George E. Wukelic

Organization: Pacific Northwest Laboratory
P.O. Box 999
Richland, Washington 99352
(509) 376-5860 (FTS: 444-5860)

Project Goals: Ensure the environmental acceptability of promising STES concepts prior to their commercialization.

Project Status: This project was established within the STES Program in FY-1980 and is expected to exist throughout the program's lifetime. Current emphasis is on: 1) developing environmental documentation for NEPA compliance, 2) guiding environmental activities of Aquifer Thermal Energy Storage (ATES) testing and demonstration projects, and 3) evaluating research results for environmental impacts and mitigation implications pertinent to commercialization feasibility.

During FY-1980, intra and interagency environmental coordination was initiated to clarify the type and contents of NEPA documentation required and external contracts established to assist PNL in their preparation. A preliminary draft Environmental Assessment (EA) for ATES has been completed, reviewed by appropriate offices and is scheduled for publication in early FY-1981. Plans for site-specific environmental assessment and monitoring activities have been cooperatively developed with ATES demonstration contractors to ensure responsiveness to the regulations of the Council on Environmental Quality and the NEPA implementation guidelines of DOE prior to full-scale demonstration activities in FY-1983.

Contract Number: DE-AC06-76RLO 1830

Contract Period: Continuing

Funding Level: \$95,000, FY-1980, B/O

Funding Source: U.S. Department of Energy, Office of Advanced Conservation Technologies

PROJECT SUMMARY

Project Title: Programmatic Environmental Assessment (Documentation)

Principal Investigator: Donald W. Lee

Organization: Oak Ridge National Laboratory
P.O. Box X
Oak Ridge, Tennessee 37830
(615) 574-5803

Project Goals: Assist PNL in preparing the Programmatic Environmental Assessment and associated environmental documentation for the Aquifer Thermal Energy Storage Program.

Project Status: The preliminary draft of the Programmatic Environmental Assessment has been completed and steps to finalize the document are progressing. The document is intended to be responsive to the regulations of the Council on Environmental Quality and the NEPA implementation guidelines of DOE.

The scoping process, prior to document preparation was directed towards identifying the alternatives to ATEs, the significant environmental issues related to ATEs and its alternatives, and the assessment methodology to be used in the document's preparation.

Preliminary conclusions indicate that ATEs technology is more developed to support testing and demonstration than its alternatives. Assessment of initially planned field activities identified no significant adverse environmental impacts. Potential environmental consequences are site-specific, and the implementation of a monitoring program with associated initiatory procedures is recommended to reduce the occurrence of any adverse environmental impact.

Contract Number: DE-AC06-76RLO 1830, W-7405-ENG-26, Purchase Order B-93958-A-0

Contract Period: 15 January 1980 through 30 September 1980

Funding Level: \$60,000

Funding Source: U.S. Department of Energy through Pacific Northwest Laboratory

PROJECT SUMMARY

Project Title: Environmental Analysis/Consulting

Principal Investigator: Heather E. McCartney

Organization: Resource Management and Assessment
P.O. Box 981
Everett, Washington 98201
(206) 258-1980

Project Goals: To provide environmental consulting services in connection with the development of environmental documentation and research efforts required to support PNL's STES Program.

Project Status: This project was established in the last quarter of FY-1980. To date, services have been provided relating to: 1) preparation of the draft programmatic environmental assessment of ATES (jointly with ORNL and PNL) and 2) development of environmental assessment and monitoring plans for the ATES demonstration projects.

In addition to the general Environmental/Institutional Plans required for each of the three demonstration projects (Bethel, Alaska; Minneapolis, Minnesota; and Stony Brook, New York), separate environmental assessment and monitoring plans for Phase I (Aquifer Characterization and Preliminary Testing) activities have been developed to identify and minimize potential environmental problems, to facilitate accumulation of needed environmental information and to fulfill NEPA requirements, CEQ regulations, and DOE guidelines for compliance with NEPA. Site-specific environmental issues are identified; monitoring plans and mitigating strategies are presented to address these issues.

Contract Number: DE-AC06-76RLO 1830, Subcontract B-B2411-A-0

Contract Period: 5 August 1980 through 15 February 1981

Funding Level: \$15,000

Funding Source: U.S. Department of Energy through Pacific Northwest Laboratory

PROJECT SUMMARY

Project Title: Field Test Facility

Principal Investigator: David A. Myers

Organization: Pacific Northwest Laboratory
P.O. Box 999
Richland, Washington 99352
(509) 375-2462 (FTS: 444-7511 ext. 2462)

Project Goals: To test and demonstrate the storage of thermally altered ground water in aquifer systems.

Project Status: A contract has been placed with Auburn University to test the feasibility of storing energy in an aquifer system at 55°, 90° and 125°C.

A test drilling and site exploration program was carried out at a site near Bellingham, Washington. Two wells were drilled into glacial deposits in an attempt to interrupt the "Esperance Sand." The nature of the glacial valley and the availability of an energy source within economical transport distance led to termination of this effort in April 1980.

Efforts to establish an FTF at Richland, Washington included drilling of seven exploratory wells. These wells tapped the shallow unconfined glaciofluvial sediments of the Pasco Basin. A parallel design effort was carried out to cover the surface equipment necessary to provide the energy for injection. Conceptual design criteria were developed for both high- and low-temperature FTFs.

At this time, negotiations are underway with the University of Minnesota to utilize the site and equipment developed by the demonstration program for extended field tests. Tests would include extended injections of 150°C water into the Franconia-Ironton-Galesville aquifer system.

Contract Number: DE-AC06-76RLO 1830

Contract Period: Continuing

Funding Level: \$70,400, FY-1980, B/O

Funding Source: U.S. Department of Energy, Office of Advanced Conservation Technologies

PROJECT SUMMARY

Project Title: Mobile, Alabama Field Test Facility

Principal Investigator: Fred J. Molz, A. David Parr and Joel G. Melville

Organization: Water Resources Research Institute
Auburn University, Alabama 36830
(205) 826-4320

Project Goals: To investigate the feasibility of storing thermal energy in confined aquifers by designing, developing, operating and analyzing data for a doublet well system.

Project Status: Work on the construction of a new well field at the Mobile field site is nearly complete. When completed, the well field will consist of 28 observation wells of various types (hydraulic head, temperature, and tracer) and three pumping wells. The new supply and injection wells will be screened in the same aquifer and separated by approximately 800 feet.

Three, 6-month, injection-storage-recovery cycles are planned. Tentative injection temperatures are 55°, 90° and 125°C, respectively. Ground-water temperatures in the storage formation will be monitored at six locations in each of 13 observation wells and at two locations in the upper and lower aquitard.

During the injection phase of each cycle, water will be pumped from the supply well, heated and injected approximately 800 feet away. After a minimum of 2 months of storage, recovery pumping will begin and water will be pumped from the injection well and returned to the supply well so that as much heat as possible can be saved between cycles.

During the first injection-storage-recovery cycle a tracer experiment will be performed. Sodium-Bromide will be injected with the heated water at a constant concentration and monitored in four tracer observation wells. Tracer concentration and temperature profiles can then be compared. In addition, land surface elevation measurements will be made along with aquifer matrix and ground-water sampling.

It is expected that the first cycle will begin in early January of 1981.

Contract Number: DE-AC06-76RLO 1830, Subcontract B-67770-A-O

Contract Period: 26 March 1980 through 31 December 1982

Funding Level: \$1,087,097

Funding Source: U.S. Department of Energy through Pacific Northwest Laboratory

PROJECT SUMMARY

Project Title: Site Exploration and Characterization near Bellingham, Washington

Principal Investigator: Carl A. Johnson

Organization: Fugro, Inc.
3777 Long Beach Blvd.
Long Beach, California 90807
(213) 595-6611

Project Goals: To characterize and assess the potential energy storage capability of a saline aquifer near Bellingham, Washington.

Project Status: This effort was terminated in April 1980. FY-1980 activities included the drilling of two deep wells in the Nooksak River Basin in an attempt to intercept the "Esperance Sand" which is thought to be present in the area. The project was terminated after drilling efforts failed to identify a usable aquifer system within economical transport distances of the proposed energy source. Energy was to have been supplied by the Thermal Reduction Company of Bellingham, Washington from their refuse burning facility.

Contract Number: DE-AC06-76RLO 1830, Subcontract B-93156-A-Z

Contract Period: 15 August 1979 through 1 May 1980

Funding Level: \$159,766

Funding Source: U.S. Department of Energy through Pacific Northwest Laboratory

PROJECT SUMMARY

Project Title: Compendia of Existing Information Task

Principal Investigator: Leigh S. Prater

Organization: Pacific Northwest Laboratory
P.O. Box 999
Richland, Washington 99352
(509) 376-4870 (FTS: 444-4870)

Project Goals: Collect, summarize, and transmit information related to Seasonal Thermal Energy Storage (STES), and maintain key data in an interactive data base.

Project Status: A useful STES library has been established. It now contains about 1400 articles with a wide range of key references on topics related to thermal energy storage.

Literature reviews and topical reports are being prepared. The topics are as follows: ATES site characterization methods, regional aquifer assessments, thermal fatigue of reservoir materials, energy and mass transport in geologic media, energy uses and sources, and reinjection experience in ground-water cooling applications.

A newsletter containing brief reports about STES projects around the world is being published quarterly by Lawrence Berkeley Laboratory.

A STES data base is being established. It will contain bibliographic information and data files generated by the STES Program components. The data base is being established on the Technology Information System (TIS) at Lawrence Livermore Laboratory.

Contract Number: DE-AC06-76RLO 1830

Contract Period: Continuing

Funding Level: \$105,300, FY-1980, B/O

Funding Source: U.S. Department of Energy, Office of Advanced Conservation Technologies

PROJECT SUMMARY

Project Title: Seasonal Thermal Energy Storage Technical Information System

Principal Investigator: Viktor E. Hampel

Organization: Lawrence Livermore Laboratory
P.O. Box 808
Livermore, California 94550
(415) 422-4357 (FTS: 532-4357)

Project Goals: To establish a comprehensive Technical Information and Communication System for the Seasonal Thermal Energy Storage (STES) Program.

Project Status: The project started in June 1980. An overall hierarchical STES data base structure has been developed. This includes the administrative, organizational, and technical description of the STES Program, its demonstration projects, and supportive activities.

The bibliography of the STES Library has been added to the data base and is available for on-line access. Over 1400 citations are contained in the bibliographic data files. On-line, customized literature searches can be conducted.

Computer equipment has been installed at the Pacific Northwest Laboratory. This equipment is being used to support the development of the STES data base.

A user's manual for the STES Technical Information System has been drafted and will be completed in FY-1981. The STES Program staff and STES contractor personnel are being trained in the use of the system.

Contract Number: DE-AC06-76RLO 1830, Subcontract B-97602-A-0

Contract Period: Continuing

Funding Level: \$122,700, FY-1980,

Funding Source: U.S. Department of Energy through Pacific Northwest Laboratory

PROJECT SUMMARY

Project Title: Maintenance and Development of the Seasonal Thermal Energy Storage (STES) Library

Principal Investigator: Charles H. Lee

Organization: Midwest Research Institute
425 Volker Boulevard
Kansas City, Missouri 64110
(816) 753-7600

Project Goals: Perform activities necessary for library maintenance and development, including technical abstracting and assignment of keywords.

Project Status: Operation of the STES Library is being implemented by Midwest Research Institute (MRI). One of MRI's employees, their librarian, is stationed at Battelle and is maintaining library operation. Technical support is being provided by personnel at their main office.

Contract Number: DE-AC06-76RLO 1830, Subcontract B-97521-A-0

Contract Period: 5 August 1980 through 30 September 1981

Funding Level: \$147,815

Funding Source: U.S. Department of Energy through Pacific Northwest Laboratory

BEST DOCUMENT AVAILABLE

PROJECT SUMMARY

Project Title: Publication of the Seasonal Thermal Energy Storage (STES) Newsletter

Principal Investigator: Chin Fu Tsang

Organization: Lawrence Berkeley Laboratory
Berkeley, California 94720
(415) 486-4000 ext. 5782

Project Goals: To organize, solicit, edit, and publish a quarterly International ATES Newsletter.

Project Status: The International ATES quarterly Newsletter is published as scheduled. Much enthusiasm both in the United States and abroad is apparent from the many contributions to and the requests for this publication. After much consideration and discussion with Pacific Northwest Laboratory, the DOE Field Manager for this project, we have decided, beginning with the September 1980 issue, to expand the Aquifer Thermal Energy Storage (ATES) Newsletter to the Seasonal Thermal Energy Storage (STES) Newsletter so that research into other means of seasonal storage will be included.

Contract Number: DE-AC06-76RLO 1830, Subcontract B-67762-A-Z

Contract Period: 1 October 1979 through 30 September 1980

Funding Level: \$25,000

Funding Source: U.S. Department of Energy through Pacific Northwest Laboratory

PROJECT SUMMARY

Project Title: Survey of Ground-Water ReInjection Experience in Air Conditioning Applications

Principal Investigator: Charles H. Lee

Organization: Midwest Research Institute
425 Volker Boulevard
Kansas City, Missouri 64110
(816) 753-7600

Project Goals: Conduct a nation-wide survey of air conditioning operations that use ground-water reinjection.

Project Status: The survey has been completed. Basically, the work consisted of three tasks: site identification, documentation of selected sites, and analysis of site data.

A final report containing results of the survey was submitted to PNL during August 1980. This report has information on 45 sites. The site analysis showed that operational problems were caused by plugging and thermal pollution. Plugging problems were caused by oxidation of Fe and Mn.

Contract Number: DE-AC06-76RLO 1830, Subcontract B-78986-A-0

Contract Period: 25 March 1980 through 15 September 1980

Funding Level: \$29,490

Funding Source: U.S. Department of Energy through Pacific Northwest Laboratory

BEST DOCUMENT AVAILABLE

PROJECT SUMMARY

Project Title: Regional Aquifer Assessment Study

Principal Investigator: Dorothy Stoffel

Organization: Century West Engineering
North 1010 Washington
Spokane, Washington 99201
(509) 326-4227

Project Goals: Qualitatively describe the Aquifer Thermal Energy Storage (ATES) potential of major aquifers throughout the United States.

Project Status: Century West Engineering has collected existing geohydrologic data for major U.S. aquifers. These data have been used to evaluate the ATES potential of each aquifer. A report containing the aquifer evaluations is currently being prepared.

Contract Number: DE-AC06-76RLO 1830, Subcontract B-93966-A-0

Contract Period: 29 March 1980 through 22 September 1980

Funding Level: \$38,317

Funding Source: U.S. Department of Energy through Pacific Northwest Laboratory

PROJECT SUMMARY

Project Title: Document on Aquifer Thermal Energy Storage Site Characterization Methods

Principal Investigator: David D. Hostetler

Organization: David D. Hostetler, Consulting Engineer
P.O. Box 151
Cannon Beach, Oregon 97110
(503) 436-2650

Project Goals: Produce a document outlining site characterization methods for an aquifer thermal energy storage facility.

Project Status: The draft report is being prepared and will be completed by September 12, 1980. The final report is due on September 30, 1980.

Contract Number: DE-AC06-76RLO 1830, Subcontract B-93986-A-0

Contract Period: 1 August 1980 through 30 September 1980

Funding Level: \$8,840

Funding Source: U.S. Department of Energy through Pacific Northwest Laboratory

PROJECT SUMMARY

Project Title: Survey of Ground-Water Source Heat Pump Operations in the Portland Area

Principal Investigator: Gordon Reistad

Organization: Department of Mechanical Engineering
Oregon State University
Corvallis, Oregon 97331
(503) 754-2575

Project Goals: Assess the use of ground-water source heat pumps for large-scale heating and cooling operations in the Portland area, and assess the potential benefit of using aquifer thermal energy storage in conjunction with heat pumps.

Project Status: The survey of heat pump operations in the Portland area has been completed. Thirteen installations were identified, and six of them were selected for documentation. Information on these six installations is contained in a report submitted to PNL during August 1980.

An assessment of the benefit of using aquifer thermal energy storage in conjunction with heat pumps is in progress and will be completed in November 1980.

Contract Number: DE-AC06-76RLO 1830, DE-AM06-76RLO2227, Task Order DE-AT06-79RL10121

Contract Period: 26 September 1979 through 30 September 1980

Funding Level: \$30,000

Funding Source: U.S. Department of Energy, Richland Operations Office

PROJECT SUMMARY

Project Title: Laboratory Analysis

Principal Investigator: James A. Stottlemyre

Organization: Battelle, Pacific Northwest Laboratory
P.O. Box 999
Richland, Washington 99352
(509) 375-2733 (FTS: 444-7511 ext 2733)

Project Goals: Investigate the potential for the causes of significant STES-induced changes in reservoir physical and chemical properties. Primary emphasis is on permeability, injectivity, and water quality.

Develop equipment and procedures necessary to support drafting of site specific reservoir design and operating criteria and environmental assessment reports.

Project Status: The project is only partially completed. Activity has focused on three tasks including laboratory equipment development, mobile field equipment development, and laboratory analysis of the effects of temperature on sand and sandstone permeability.

A contract has been awarded to Terra Tek, Inc. to design and construct a laboratory scale apparatus capable of testing reservoir materials and associated ground waters under simulated STES operating conditions, e.g., time-varying temperatures, stresses and flow rates. Emphasis is on permeability, porosity, strain (sample deformation), mineralogy, particle carry-over, and water quality. Completion of the equipment is scheduled for June 1981.

A contract has been awarded to Terra Tek, Inc., to develop a mobile, inline, injectivity-impairment test stand for use at field sites. This equipment is designed to permit evaluation of injection well longevity as a function of injection water quality and reservoir injection parameters. Completion of the equipment is tentatively scheduled for December 1980. A report covering the motivations for and techniques of injection well impairment testing has been drafted and is undergoing PNL/DOE review.

Several experiments have been conducted at Terra Tek and PNL concerning the effects of temperature on sand and sandstone permeability to water. Preliminary observations are that significant permeability reductions can be expected, damage may be confined to near wellbore zones, degradation is time dependent and transient in nature, and particulate plugging appears to be the principle cause. Experiments are continuing and a draft report will be issued this fall.

Contract Number: DE-AC06-76RLO 1830

Contract Period: Continuing

Funding Level: \$66,000, FY-1980, B/O

Funding Source: U.S. Department of Energy, Office of Advanced Conservation Technologies

PROJECT SUMMARY

Project Title: Flow Facility Development and Laboratory Analysis

Principal Investigator: Craig H. Cooley, Larry Owens

Organization: Terra Tek, Inc.
420 Wakara Way
Salt Lake City, UT 84108
(801) 582-2220

Project Goals: Develop laboratory and field flow facilities for evaluation of water injectability in order to predict the long term response of aquifers to thermal energy storage.

Project Status: This project is on-going. A combined laboratory and field program has been designed. The laboratory flow facility will be built to test core under simulated ATES reservoir conditions. A field flow apparatus will be built to evaluate the injectability of fluids.

Modification of an existing Terra Tek laboratory flow facility was undertaken to test design concepts and provide early data.

Flow tests have been conducted with this apparatus on Massillon sandstone and 150/170 mesh Ottawa silica sand. Pore fluids included brine and deionized water, temperatures were 25°C to 150°C, and confining and pore pressures were 150 bars and 60 bars respectively.

Final specifications and design concepts have been determined for the laboratory flow facility.

A portable field flow facility with semi-automated apparatus for the evaluation of fluid injectability ($\leq 200^\circ\text{C}$; ≤ 1000 psi) has been designed. The design concept is based on the use of membrane filters or core plugs, with the appropriate pore size distribution, as analogs of the injection formation. The specifications for the test apparatus provide for the performance of two simultaneous tests to permit evaluation of the effects of ATES thermal cycling on injectability.

Standard operating procedures will be developed. HP-67-compatible software will be developed to permit field analysis of test data by the Barkman and Davidson water quality method. Field tests will be performed at one ATES test site and the operation's personnel at that site will be trained to utilize the test apparatus on a routine basis.

Major conclusions are that the design concepts and specifications for the laboratory and field flow systems are valid, and the early data obtained will help in understanding water injectability and production changes resulting from ATES.

Contract Number: DE-AC06-76RLO 1830, Subcontracts B-96462-A-D; B-82282-A-H; 78992 AD (in negotiation)

Contract Period: 1 October 1979 to 30 September 1980

Funding Level: \$115,000

Funding Source: U.S. Department of Energy through Pacific Northwest Laboratory

PROJECT SUMMARY

Project Title: Numerical Simulation

Principal Investigator: Charles T. Kincaid

Organization: Battelle, Pacific Northwest Laboratory
P.O. Box 999
Richland, Washington 99352
(509) 375-2867 (FTS: 444-7511 ext 2867)

Project Goals: Provide technical support in the form of numerical simulation techniques capable of assessing the performance and impacts of aquifer thermal energy storage (ATES).

Within PNL this subtask is to establish a responsive, internal capability for the simulation of ATES facilities. Externally we are utilizing the best available technology to advance the state-of-the-art and provide the necessary analysis capabilities for the engineering community.

Project Status: A responsive simulation modeling capability is being developed through the joint efforts of internal staff and an external contractor. A multi-dimensional ground-water simulation model has been broadened to include the transport of both energy and conservative solute. The code combines the finite element method with an uncoupled solution scheme. A substantial effort has been made to produce a user oriented analysis tool. Specifically, a graphics package has been developed for the display of both initial information and analysis results.

This effort toward the establishment of a confined aquifer modeling capability for the flow of fluid and energy is approximately 80% complete. Major augmentation to the previous ground-water analysis package is complete. Verification employing published solutions is in progress. Minor alteration to both the code and its graphics package are anticipated in the areas of mesh generation and time step control.

External contracts with Washington State University and Lawrence Berkeley Laboratory compliment this work through the utilization of presently available computing methods. WSU is nearing completion of a version of Intera's DWDM code which will be appropriate for use on restricted word size machines. Several simulation modeling tasks are being conducted by LBL.

Contract Number: DE-AC06-76RLO 1830

Contract Period: Continuing

Funding Level: \$65,000, FY-1980, B/O

Funding Source: U.S. Department of Energy, Office of Advanced Conservation Technologies

PROJECT SUMMARY

Project Title: Extension of Isothermal Simulation Code to the Non-isothermal Regime

Principal Investigator: Sumant K. Gupta

Organization: George Maddox & Associates
W. 601 Mallon
Spokane, Washington 99201
(509) 326-7515

Project Goals: Extend the current ground-water analysis capability of the FE3DGW (finite element three-dimensional ground water) code to include energy and conservative solute transport. Verify the analysis through the use of published solutions to simplified analyses, and hypothetical problems of a more complex nature.

Project Status: Major modifications to the isothermal code have been completed. Current efforts focus upon the verification of the computational package.

Equations for the conservation of mass, energy, and solute mass have been reduced to an algebraic system via the finite element method. The non-isothermal influence is introduced through the density and viscosity terms. A solution is achieved via a sequential, uncoupled methodology.

Study of the mass conserving character of this analysis reveals that local conservation may be best used to judge the adequacy of mesh refinement and length of time step.

Interactive programs designed for the creation of input files have been developed. Graphics capabilities are utilized to review input as well as display output.

Present efforts focus upon verification and the determination of adequate mesh and time step resolution for accurate simulation.

Contract Number: DE-AC06-76RLO 1830, Consultant Agreement B-29028-A-L

Contract Period: 1 October 1979 through 30 September 1980

Funding Level: \$110,000

Funding Source: U.S. Department of Energy through Pacific Northwest Laboratory

PROJECT SUMMARY

Project Title: Mathematical Studies in Aquifer Thermal Energy Storage

Principal Investigator: Chin Fu Tsang

Organization: Lawrence Berkeley Laboratory
Berkeley, California 94720
(415) 486-4000 ext. 5782

Project Goals: To perform ATES generic studies, improve modeling techniques, and carry out field-specific planning and simulation studies.

Project Status: Considerable generic studies have been done during this fiscal year to study the dependence of the energy recovery factor and the recovery temperature as a function of aquifer properties, storage period, partial and full penetration, storage volume and temperature. The general conclusion is that with a proper selection of an aquifer and a carefully designed system, a good recovery can be realized. Lumped parameter groups are also identified and evaluated to be used for optimization of the system.

Work has also been initiated to improve our numerical model "CCC" so that it can more effectively handle saturated-unsaturated flow problems. This is expected to be completed during the next fiscal year.

The two-cycle Auburn field experiments (1978-1979) have been successfully simulated with the LBL numerical model "CCC". Observed and calculated recovery factors are within 2% of each other and the production temperatures are reproduced within 2°C. No adjustable parameter was used. One may conclude that a) we understand the physical processes involved in an ATES system at the Auburn field site, thus giving us confidence in dealing with confined aquifers of a similar type, and b) the LBL numerical model "CCC" is a satisfactory code that may be useful for further applications. Further calculations have been performed with this numerical model to help in the design of the next series of experiments by the Auburn University.

Contract Number: DE-AC06-76RLO 1830, Subcontract B-67762-A-Z, W-7405-ENG-48

Contract Period: 1 October 1979 through 30 September 1980

Funding Level: \$235,000

Funding Source: U.S. Department of Energy through Pacific Northwest Laboratory

PROJECT SUMMARY

Project Title: Study of Coupled Energy and Mass Transport in Geologic Media

Principal Investigator: Stuart Childs

Organization: Department of Soil Science
Oregon State University
Corvallis, Oregon 97331
(503) 754-2441

Project Goals: Examine the physical principles of energy and mass transport in geologic media, and identify soil and environmental conditions or parameters influencing the efficiency of aquifer thermal energy storage.

Project Status: A literature review on the subject of energy and mass flow through porous media has been completed. An annotated bibliography is being prepared and will contain key references identified in the literature review. A preliminary interpretive report containing information on important parameters involved in energy and mass transport in geologic media will be completed in September 1980.

Contract Number: DE-AC06-76RLO 1830, Subcontract B-97620-A-0

Contract Period: 1 July 1980 through 30 April 1981

Funding Level: \$43,660

Funding Source: U.S. Department of Energy through Pacific Northwest Laboratory

PROJECT SUMMARY

Project Title: Hydrologic Studies Support

Principal Investigator: J. W. Crosby III, Vernon Ichimura

Organization: Washington State University
Geological Engineering
Pullman, Washington 99164
(509) 335-8546

Project Goals: Alter the Intera Deep Well Disposal Model (DWDM) code to make it compatible with IBM computers without losing the accuracy apparent in runs made on CDC computers.

In addition to the basic comparison of old and new codes, an analysis will be made of the Mobile, Alabama test facility's two experiments performed between March 1978 and April 1979. Comparison of computed results will be made with data from the experiments.

Project Status: Of the two stated project goals, the first is nearing completion while the latter is in its infancy.

Truncation errors, resulting from the use of shorter word length processing, have been identified with the mass and energy balance algorithms of the Intera code. Increased precision in selected arrays and calculations have largely alleviated these difficulties. Published solutions have been employed to verify the altered algorithms. A fully double precision version of the Intera code is being developed for further comparisons. Test problems involving relatively large quantities of energy show much improved conservation via the budget algorithms.

A copy of the Auburn data has been received by Mr. Ichimura. He has completed transfer of the data to the WSU computer system. A graphics package has been developed for the expressed purpose of displaying not only the raw data but also the computed predictions of the Intera code. An ability to restart the code from previously stored information (from a preceding simulation) has been developed. The additional flexibility which this option affords the code will be very useful in the forthcoming analysis of the Mobile, Alabama experiments.

Contract Number: DE-AC06-76RLO 1830, DE-AM06-76RLO2221, Task Agreement No. AT06-79RL10119

Contract Period: 26 September 1979 through 31 December 1980

Funding Level: \$30,000

Funding Source: U.S. Department of Energy, Richland Operations Office

BEST DOCUMENT AVAILABLE

PROJECT SUMMARY

Project Title: Non-Aquifer Seasonal Thermal Energy Storage Concepts

Principal Investigator: Donald E. Blahnik

Organization: Pacific Northwest Laboratory
P.O. Box 999
Richland, Washington 99352
(509) 375-2954 (FTS: 444-7411 ext 2954)

Project Goals: Survey, evaluate and select non-aquifer thermal energy storage concepts for seasonal applications. If warranted, recommend further research and development that can lead to demonstration and commercialization of promising concepts.

Project Status: An initial survey, evaluation and selection of potential non-aquifer thermal energy concepts for seasonal use was completed in the first quarter of FY-1980. Results of the work were summarized in a draft report which is in process of being formalized for external distribution.

Literature was obtained and used to establish a non-aquifer STES library. The literature through September 1979 was reviewed and TES concepts were evaluated for their use in seasonal applications. The evaluation was not in depth but it covered the entire gamut of thermal energy storage concepts.

The brief evaluation indicated that sensible heat and cool concepts had the most near term promise because the state-of-the-art is more advanced. In general the best STES concepts appear to be using low temperatures (<95°C), low cost storage media (water and rock), construction with earth, good insulation, and economies of large scale.

In FY-1981 it is planned to update the literature survey and concept evaluations in the first quarter. The survey and evaluation of concepts in the literature will be kept current throughout the year along with the library. The most promising concepts will be evaluated more thoroughly, especially in the areas of cost and heat retention efficiency. A program plan will be established to develop promising concepts. A comprehensive formal report will be issued at the end of the year.

Contract Number: DE-AC06-76RLO 1830

Contract Period: Continuing

Funding Level: \$78,000, FY-1980, B/O

Funding Source: U.S. Department of Energy, Office of Advanced Conservation Technologies

U.S. GOVERNMENT PRINTING OFFICE: 1981 - 341-060 2023